Indicators of Ecological Change

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A SERDP Ecosystem Management Project (SEMP) being implemented at Fort Benning, GA

SEMP Technical Advisory Committee Meeting
October 2002

* Slide to be used in oral presentation on October 28, 20

Participants

- Jack Feminella and Kelly Maloney, Department of Biological Sciences, Auburn University — Stream macroinvertebrates
- Thomas Foster, Anthropology Department, Pennsylvania State University — Historical land cover
- Patrick Mulholland, Environmental Sciences Division, Oak Ridge National Laboratory — Aquatic ecology
- Lisa Olsen, Environmental Sciences Division, Oak Ridge National Laboratory — Geographic information and landscape analysis
- David White, Aaron Peacock, and Sarah McNaughton, Center for Environmental Technology, University of Tennessee — Soil microbiology
- Sharon Hermann and Dan Wyrick, Department of Biological Sciences, Auburn University — Terrestrial indicators
- Virginia Dale, Environmental Sciences Division, Oak Ridge National Laboratory — Terrestrial and landscape indicators, integration

Objectives

- To identify indicators that signal ecological change in intensely versus lightly used ecological systems.
- To ensure that these indicators are feasible for the installation staff to measure and interpret and thus can become a part of the ongoing monitoring system at the installa

Technical Approach

(a) Analyze historical trends in environmental changes to identify potential indicators;

(b) Collect supplemental data relating to proposed indicators (building upon existing data);

(c) Perform experiments to examine how training affects indicators;

(d) Analyze resulting set of indicators for appropriateness, usefulness, and ease of taking the measure;

(e) Develop and implement a technology transfer plan.

Suite of Ecological Indicators

Landscape | Watershed | Plot | Micro

Hierarchical Perspective

Spatial Scale

Landscape Metrics

Fragmentation contagion

Patch area

Terrestrial Ecosystems

Distribution of successional stages

Understory composition

Presence of key species

Stream Ecosystems

Storm concentration profiles

Metabolism

Macroinvertebrates

Diversity, biomass & abundance

Focal populations

Soil Microorganisms

Community composition

Microbial biomass

Physiological status

Criteria for Indicators

(From Dale, V.H and Beyeler, S.C. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators 1(1): 3-10.)

- Are easily measurable
- Are sensitive to stresses of system
- Respond to stress in a predictable manner
- Signify an impending change in key characteristics of the ecological system
- Experience changes that can be averted by management actions
- Together with the full suite of indicators, provide a measure of coverage of the key gradients across the ecological systems (e.g., soils, vegetation types, temperature, etc.)
- Have a known response to natural disturbances and changes over time

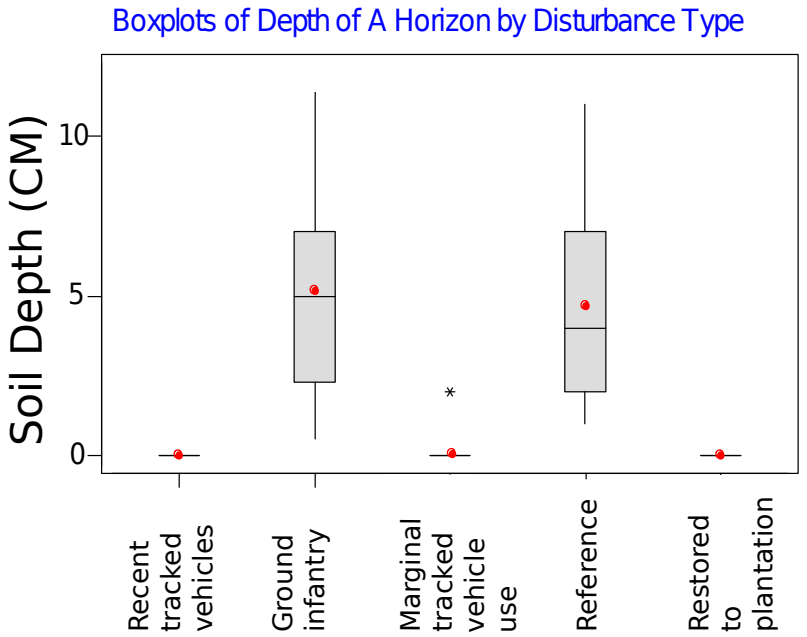
* Sampled vegetation and soil microbes in five discrete land-use types

(based on observations and experience of Fort Benning staff)

- Reference
- Ground infantry
- Marginal to tracked vehicles use
- Recent tracked vehicle use
- Restored to plantation

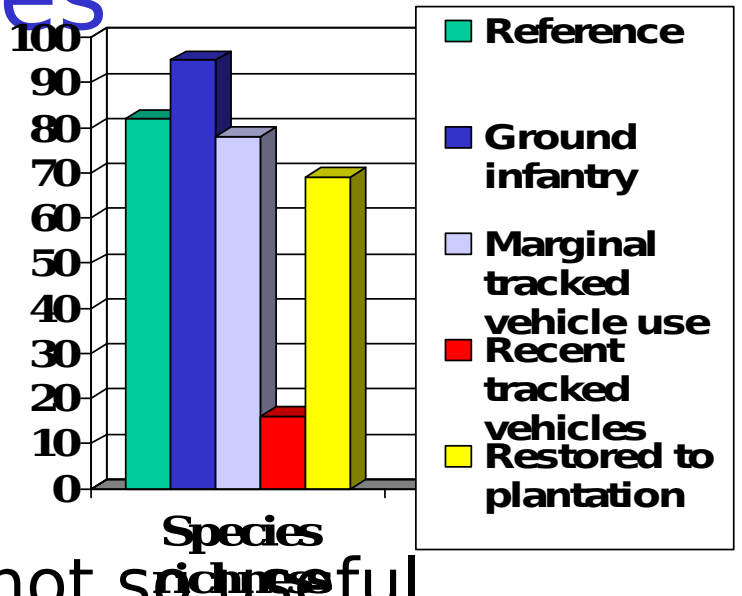
Technical Approach: Terrestrial Studies

- Objective
  - Determine indicators of ecological change due to military training
- Approach
  - Establish 5 plots along 3 transects in sites of five discrete land uses
  - Establish 5 plots along 2 transects in restored sites
  - Measure understory vegetation and microbiolo
  - Determine differences an patterns

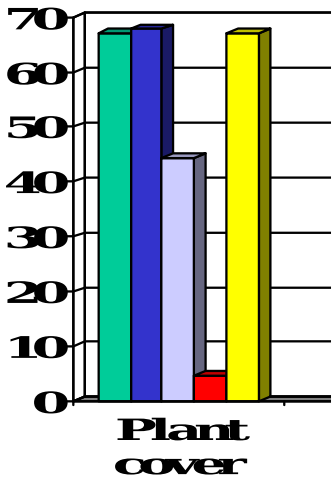


Technical Approach: Terrestrial Studies

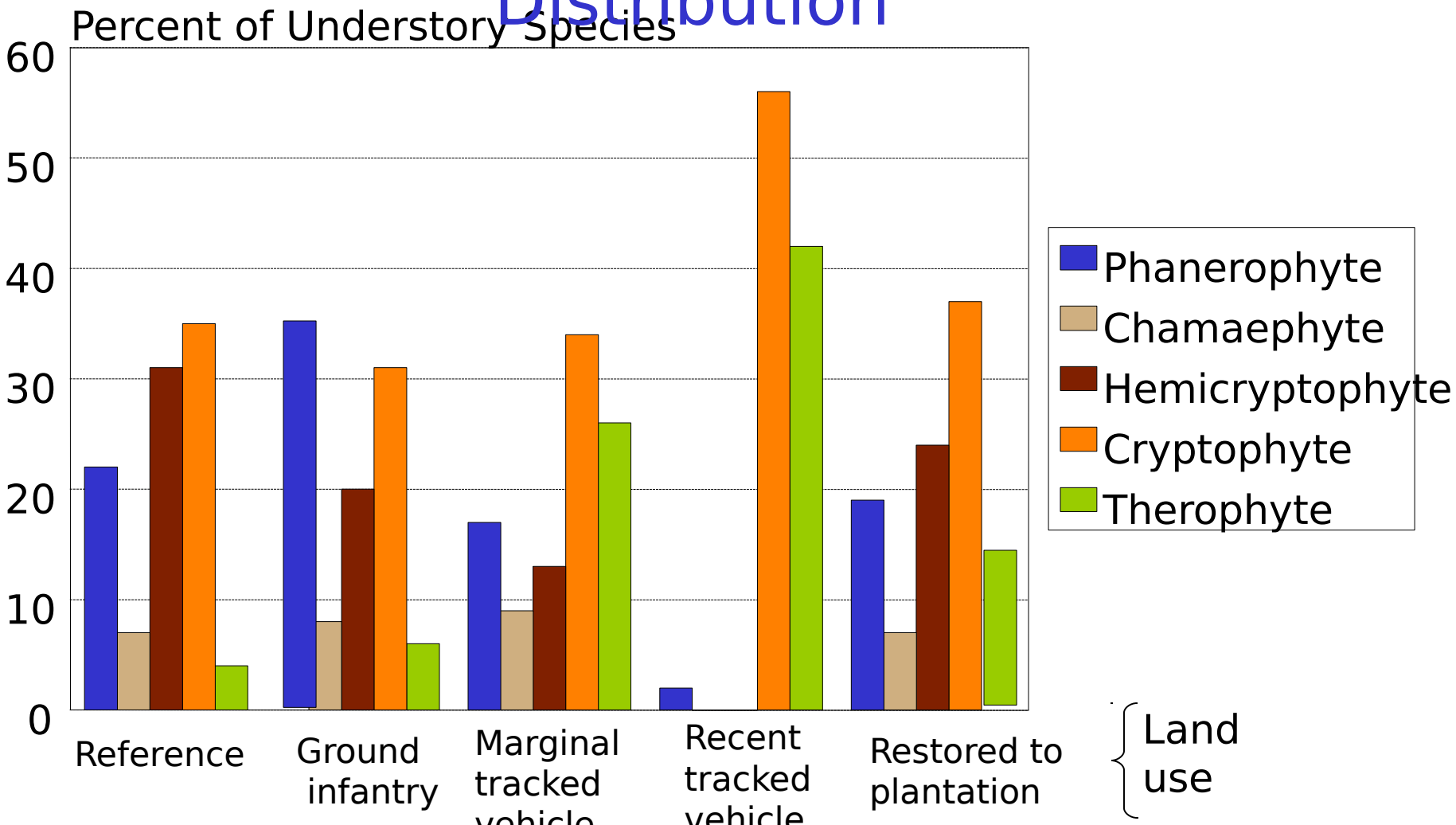
- Candidate indicators
  - Life form composition
  - Plant family composition
  - Key genera
  - Depth of A horizon



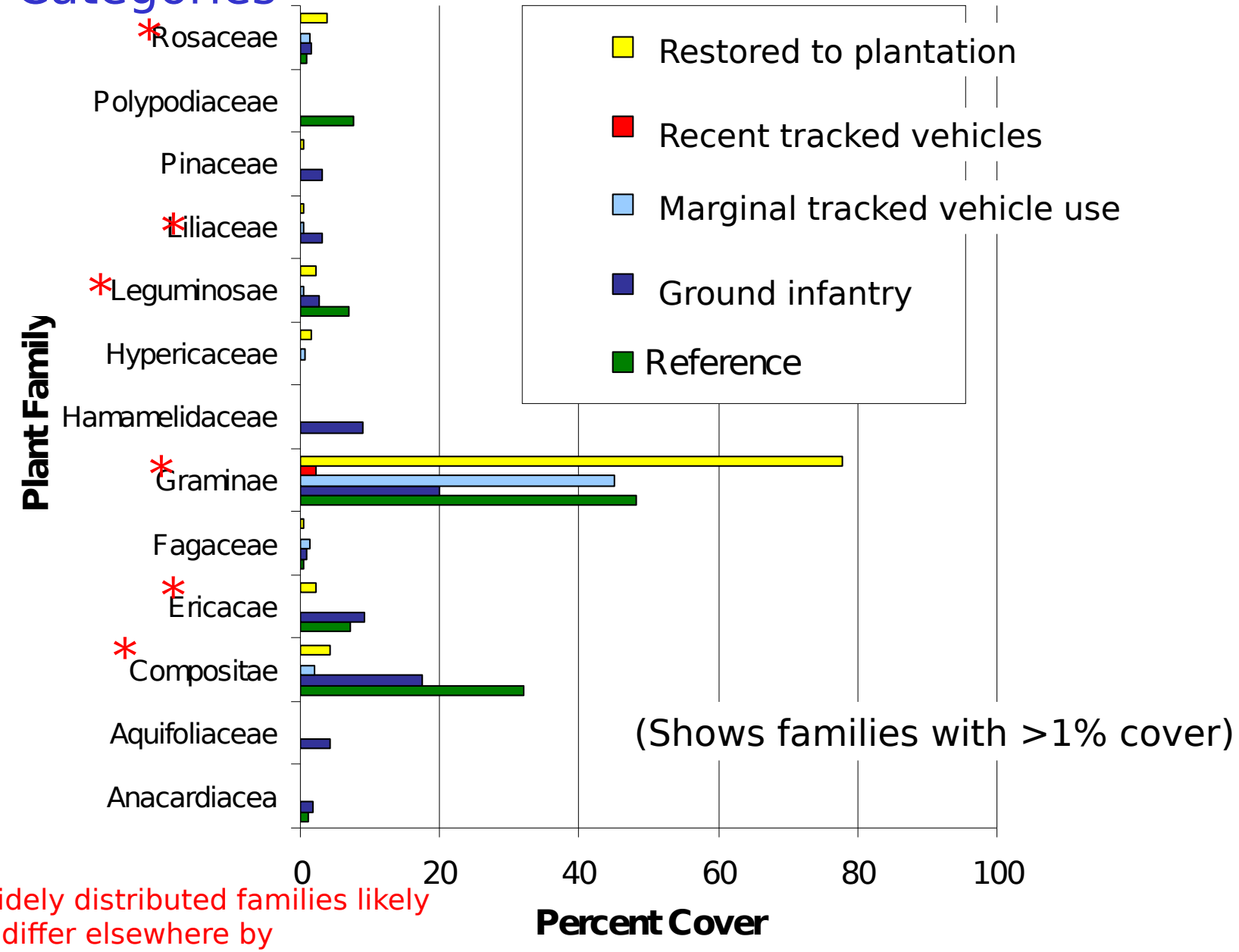
- Potential indicators that were not so useful
  - Plant cover
  - Species composition
  - Species richness



Training Categories Differ According to Life Form Distribution



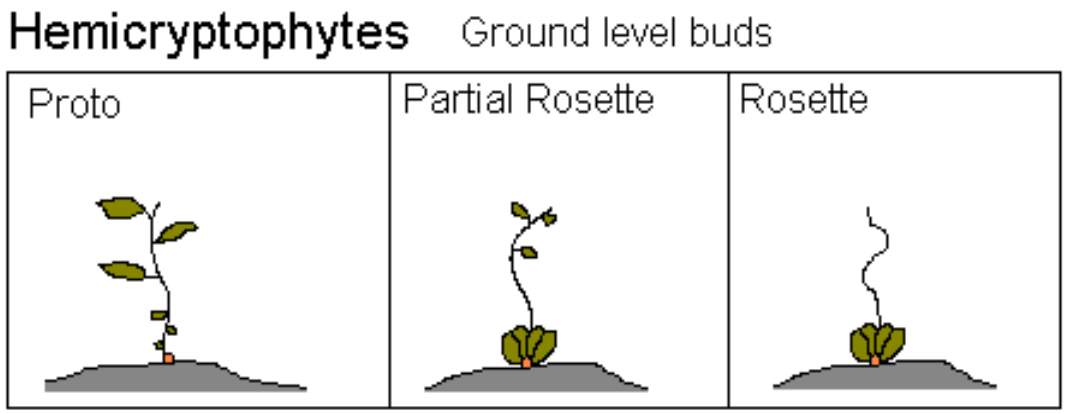
Cover of Plant Families Differs between Training Categories



*Widely distributed families likely to differ elsewhere by

Transfer of Information

Plant Families and Life Forms Seen in the Fort Benning Area: A Field Guide



Soil Chemical Biomarker Measurements For Quantitative Land-Use Impacts & End Points for Reversibility

- **Benefits:**
  - **Easy collection of soil cores**
  - **Ship frozen**
  - **Base or commercial laboratory for analysis**
  - **Readily interpretable definition and potential for reversibil**
    (Soil microbiota do not require biological expertise to in

Based on:

Exposure of pine forest surface soils to vehicular traffic - Fort Benn

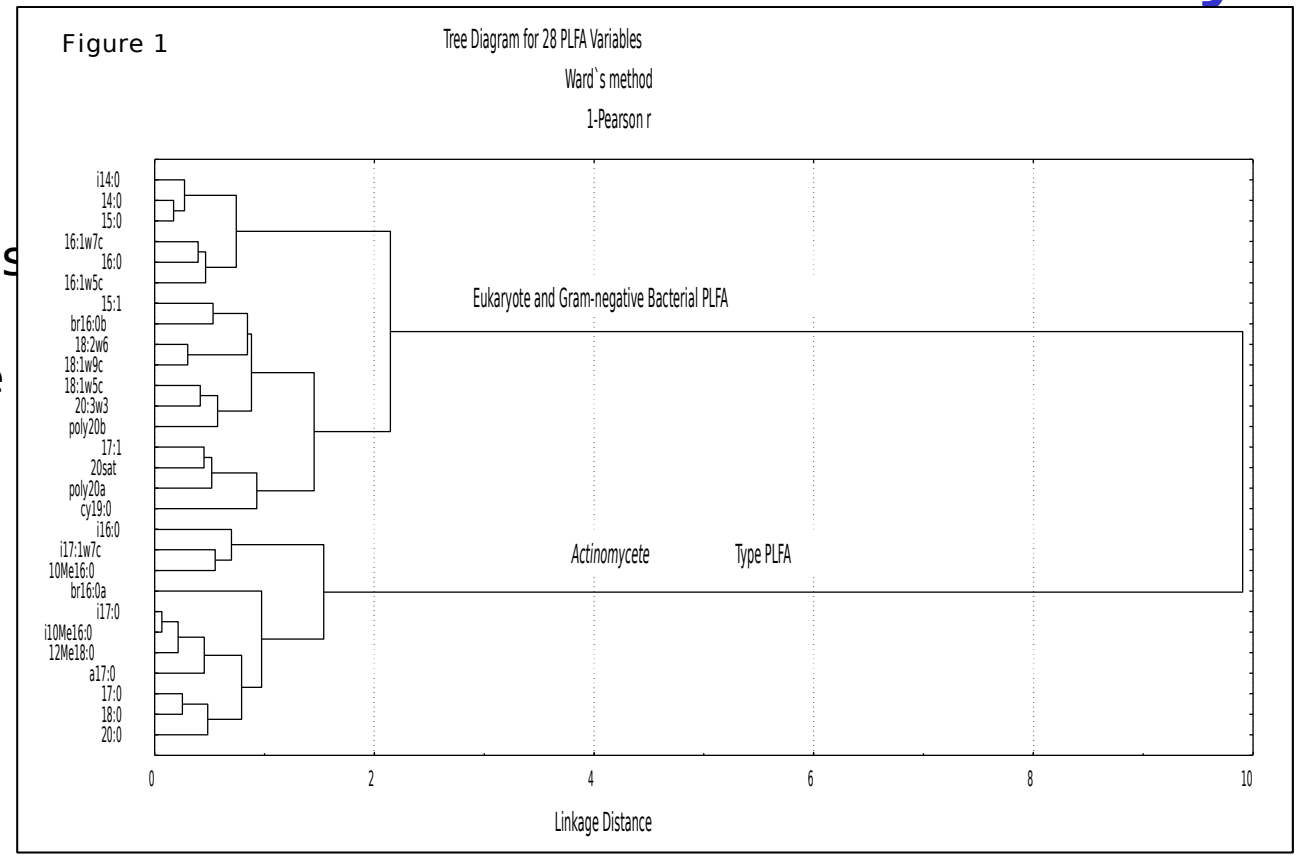
Changes in soil viable microbial biomass and composition determin from lipid biomarker analyses

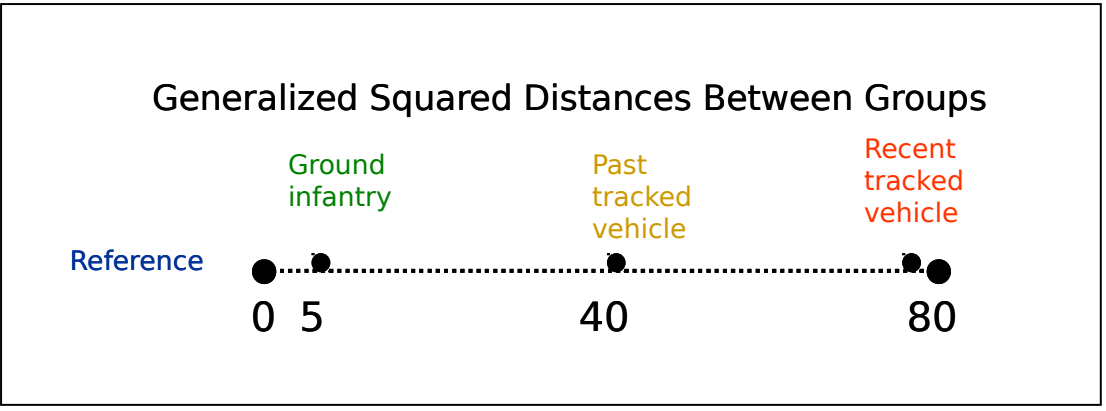
Plant communities & stream ecology responses parallel microb

Analysis of soil microbial community

Linear discriminant model using 17 phospholipid fatty acid (PLFA) predictor variables

- Reference and ground infantry transects were very similar
- Past and recent tracked vehicle use transects greatly differed

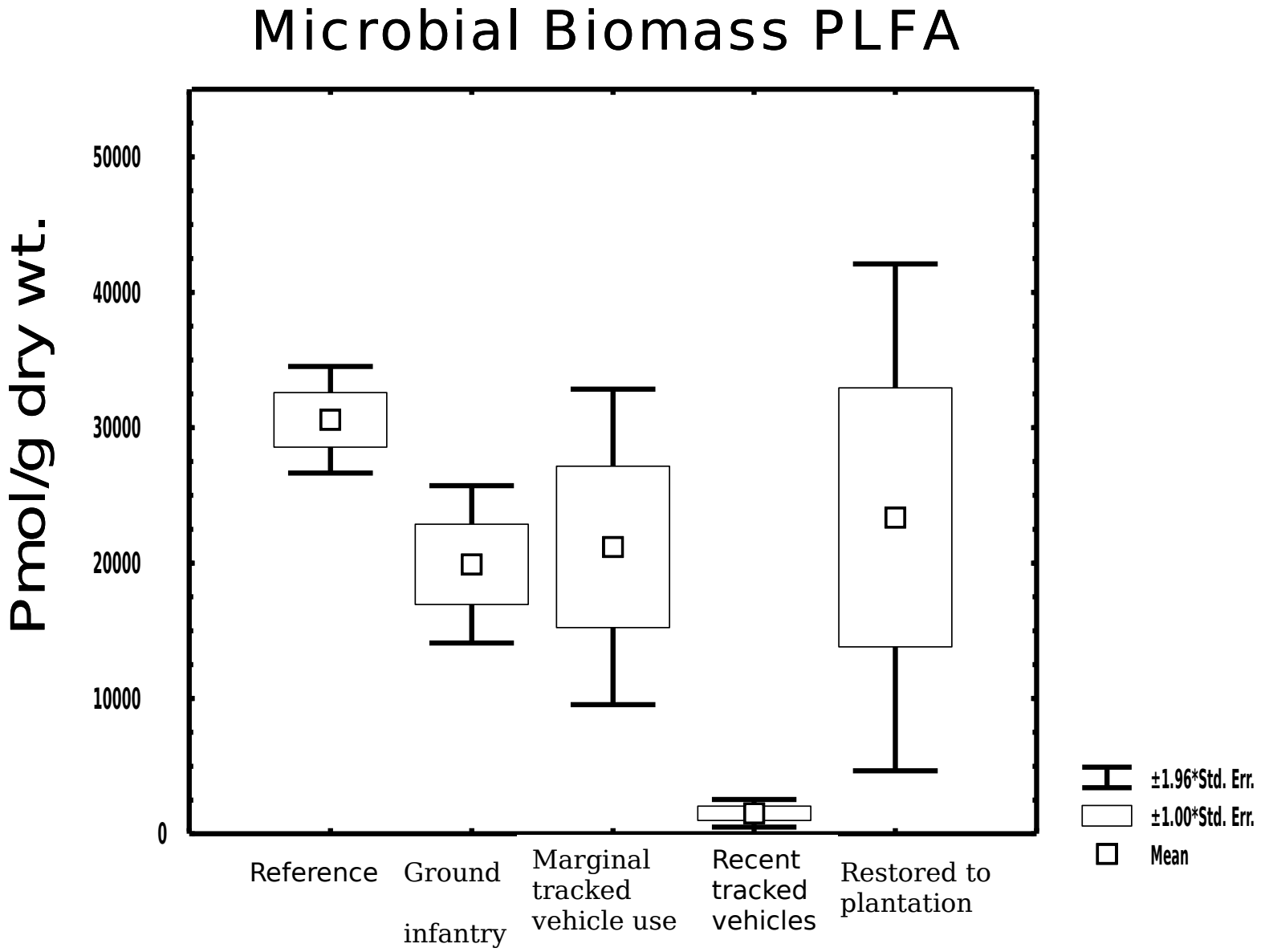




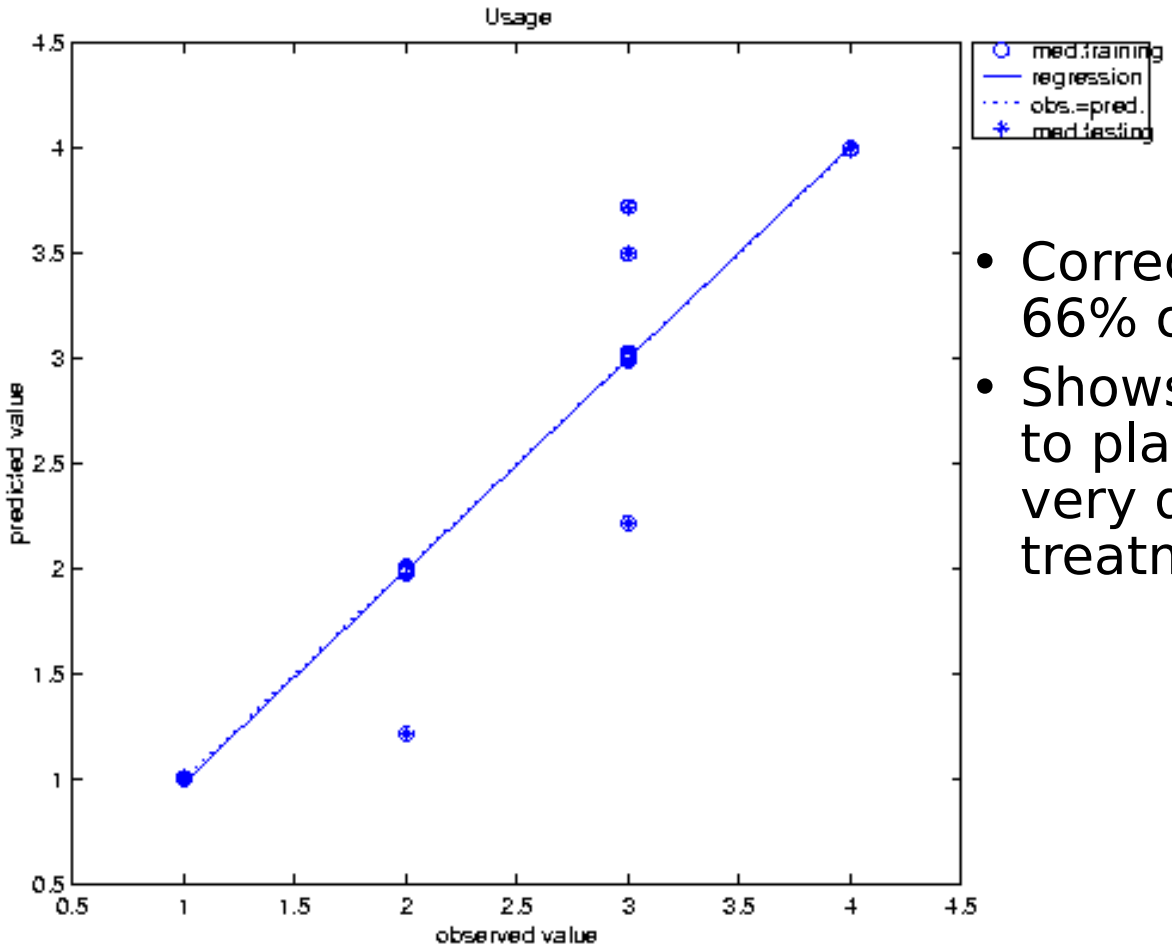
PLFAs included in the Discriminant Model

a15:0	i17:0	18:1w9c
i16:0	a17:0	18:0
16:1w7c	Cy17:0	10Me18:0
br16:0a	17:0	Cy19:0
i17:1w7c	i10Me16:0	20sat
10Me16:0	18:2w6	

The heavily used site had significantly less microbial biomass.



Non-linear Artificial Neural Network Analysis



- Correctly predicts classification 66% of the time (25% chance)
- Shows that transects restored to plantations transects are very different from all other treatments

Technical Approach: Stream Studies

Objective

Develop and evaluate potential indices of land-use effects on catchment biogeochemistry and stream ecosystems

Approach

Land-use gradient analysis (land-use intensity quantified at catchment scale as % land denuded)

- Stream sites (2nd-3rd order) over range of land-use intensity
- Measure potential indices across land-use gradient
- Develop relationships between indices and land-

Potential Stream Indices of Land Use

1. Storm chemistry profiles

Measurements: NH_4, NO_3, PO_4, Cl, SO_4, electrical conductance, suspended sediments over storm hydrographs

Analyses: concentration vs. discharge relationships, peak concentrations

2. Diel dissolved oxygen profiles (metabolism indicator)

Measurements: dissolved oxygen concentrations and deficits at 30-min intervals during baseflow

Analyses: diurnal amplitude, night-time minima

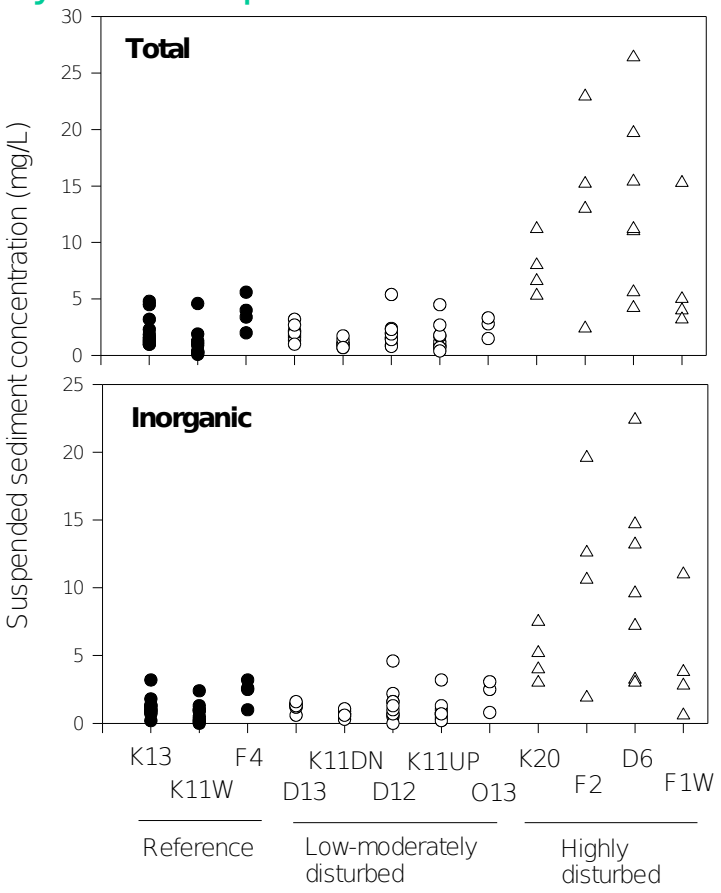
3. Macroinvertebrate communities and habitats

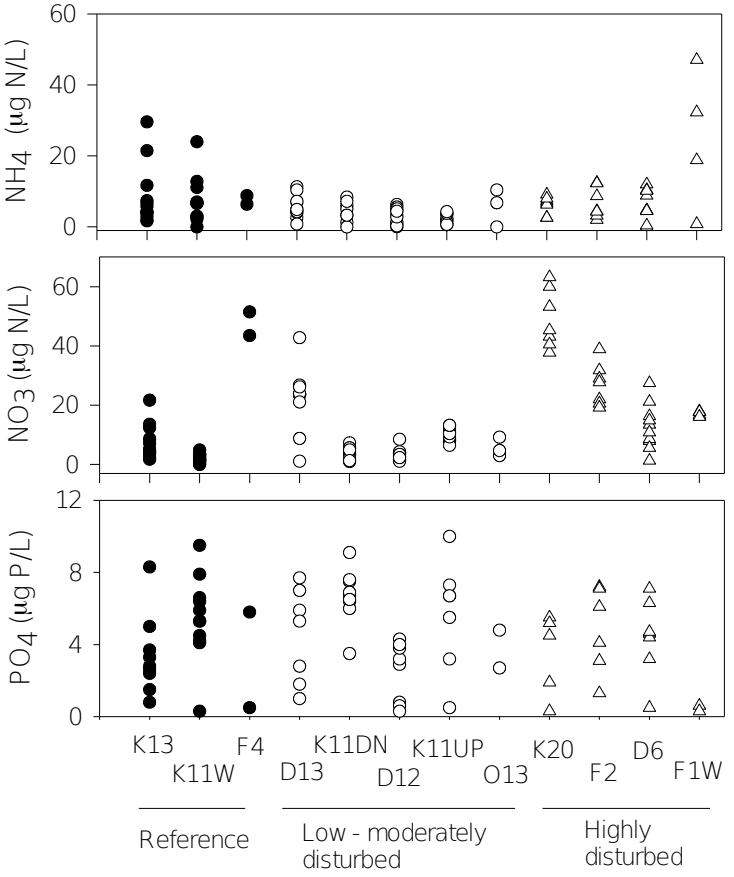
Measurements: numbers, biomass & diversity of benthic macroinvertebrates, bedload sediment movement

Analyses: EPT index, sensitive species abundance, NCBI index, similarity indices, sediment movement over time

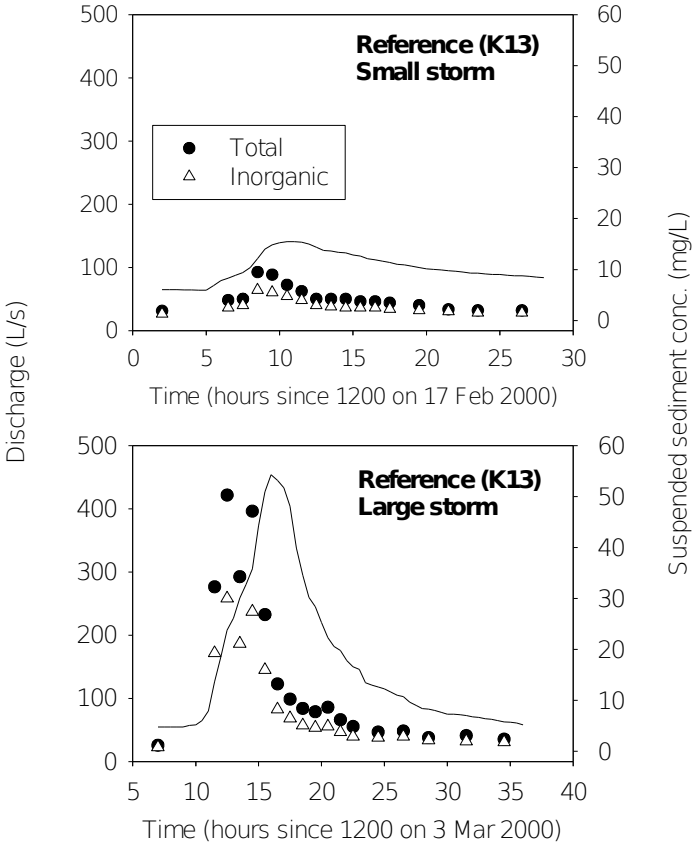
Baseflow suspended sediment concentrations are a good indicator of land use (left) but baseflow nutrient concentrations are not (right)

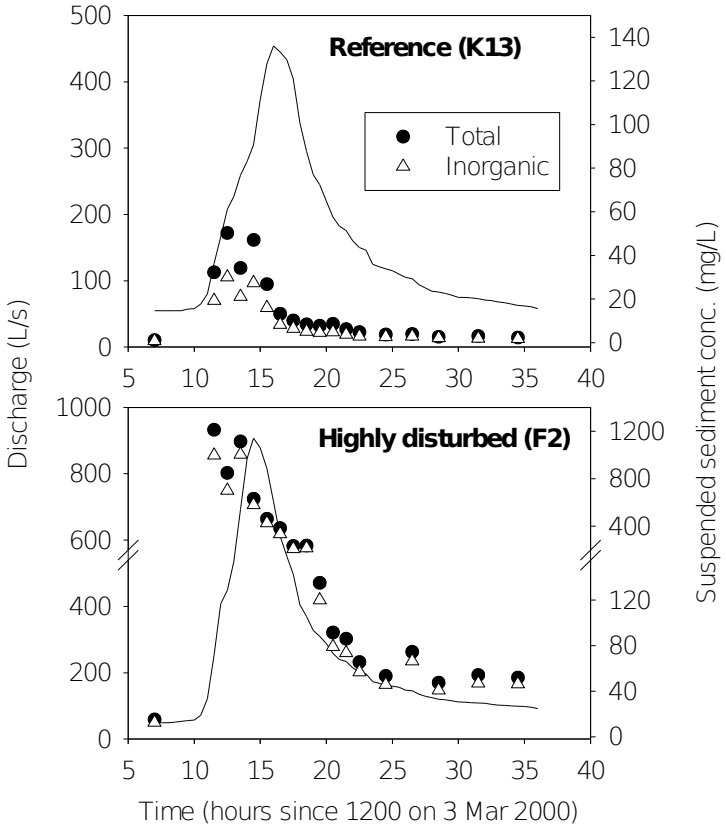
Symbols represent different storms.



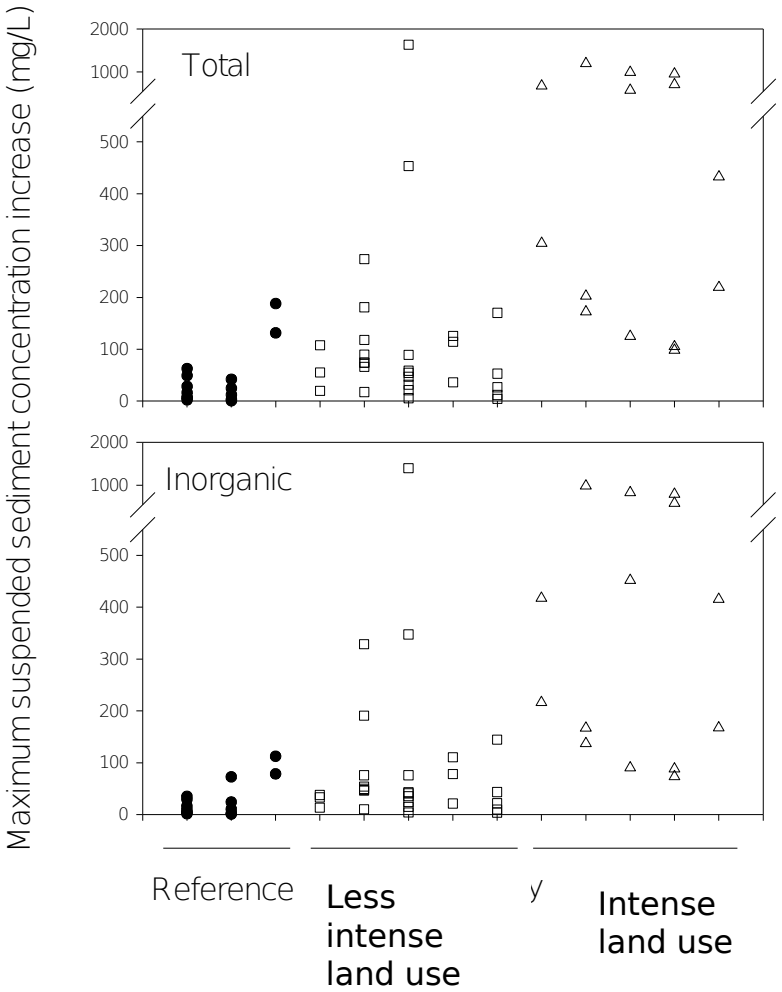


Storm increases in suspended sediment concentration are greater for larger storms (left) and are greater in streams in intensely used watersheds (right)

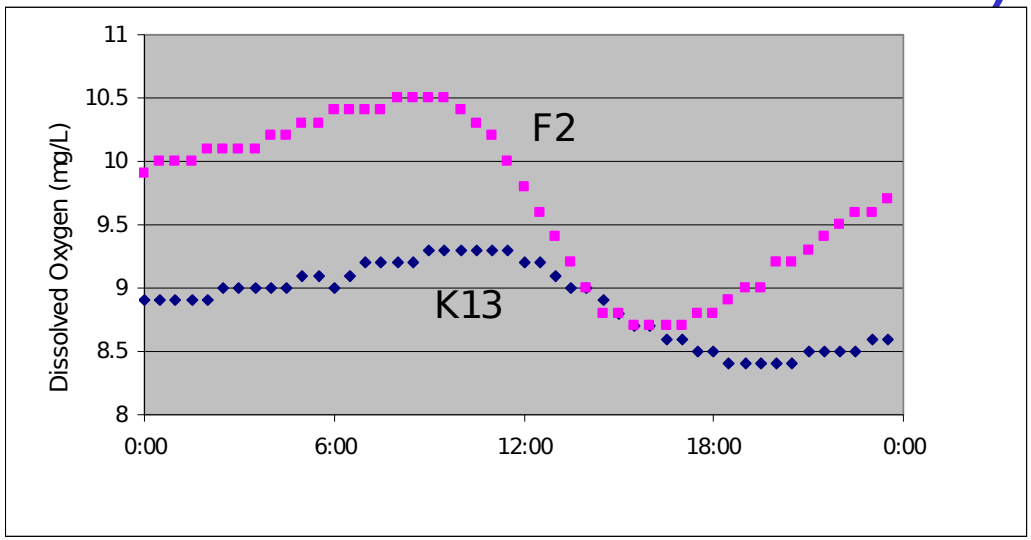


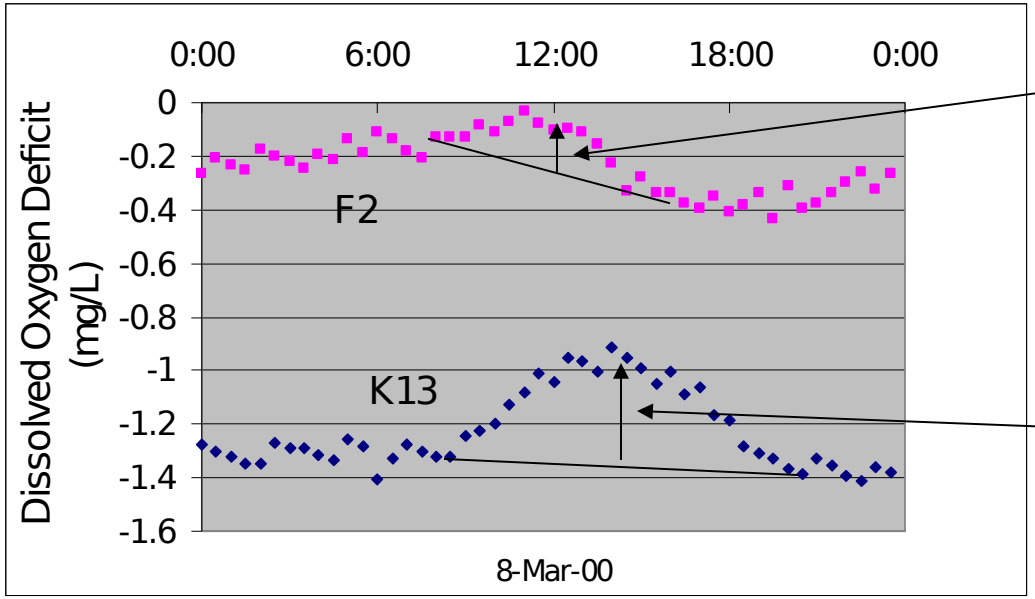


Maximum increase in suspended sediment concentration is a good indicator of land use (particularly inorganic sediments, lower panel)



Dissolved Oxygen Profiles (8 Mar 2000)



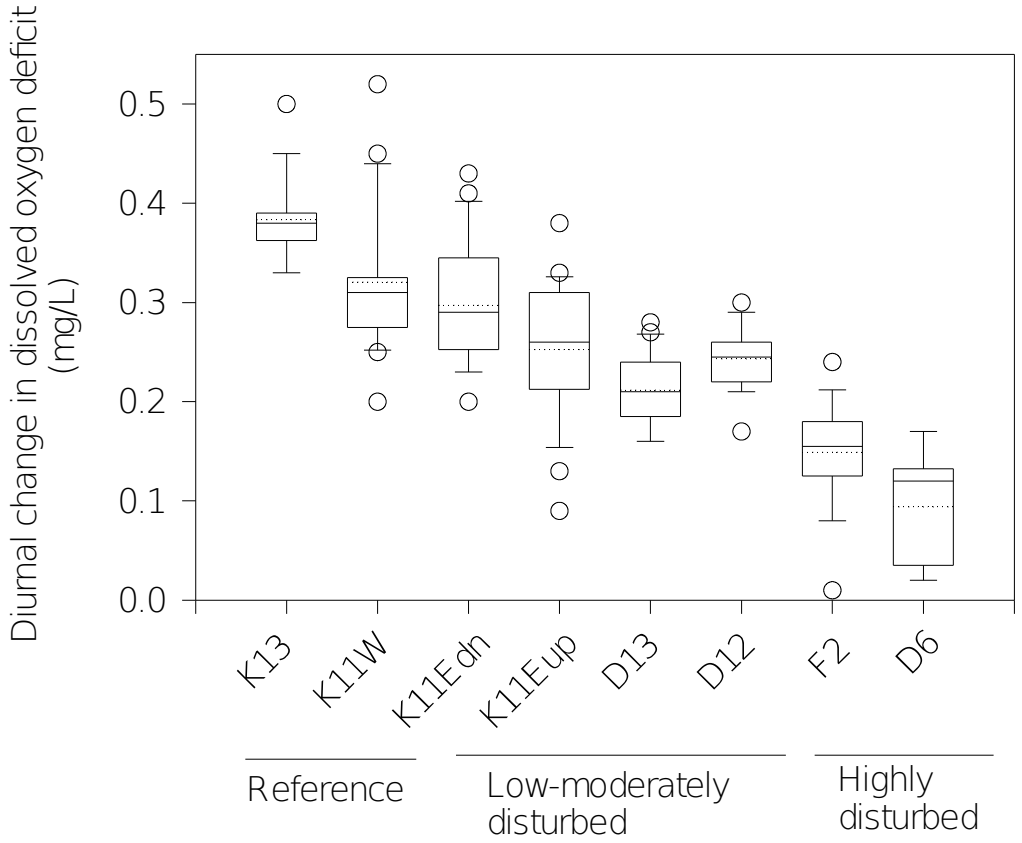


Diurnal dissolved oxygen profiles appear to be a useful land-use indicator

Low daytime primary productivity in highly used stream (F2)

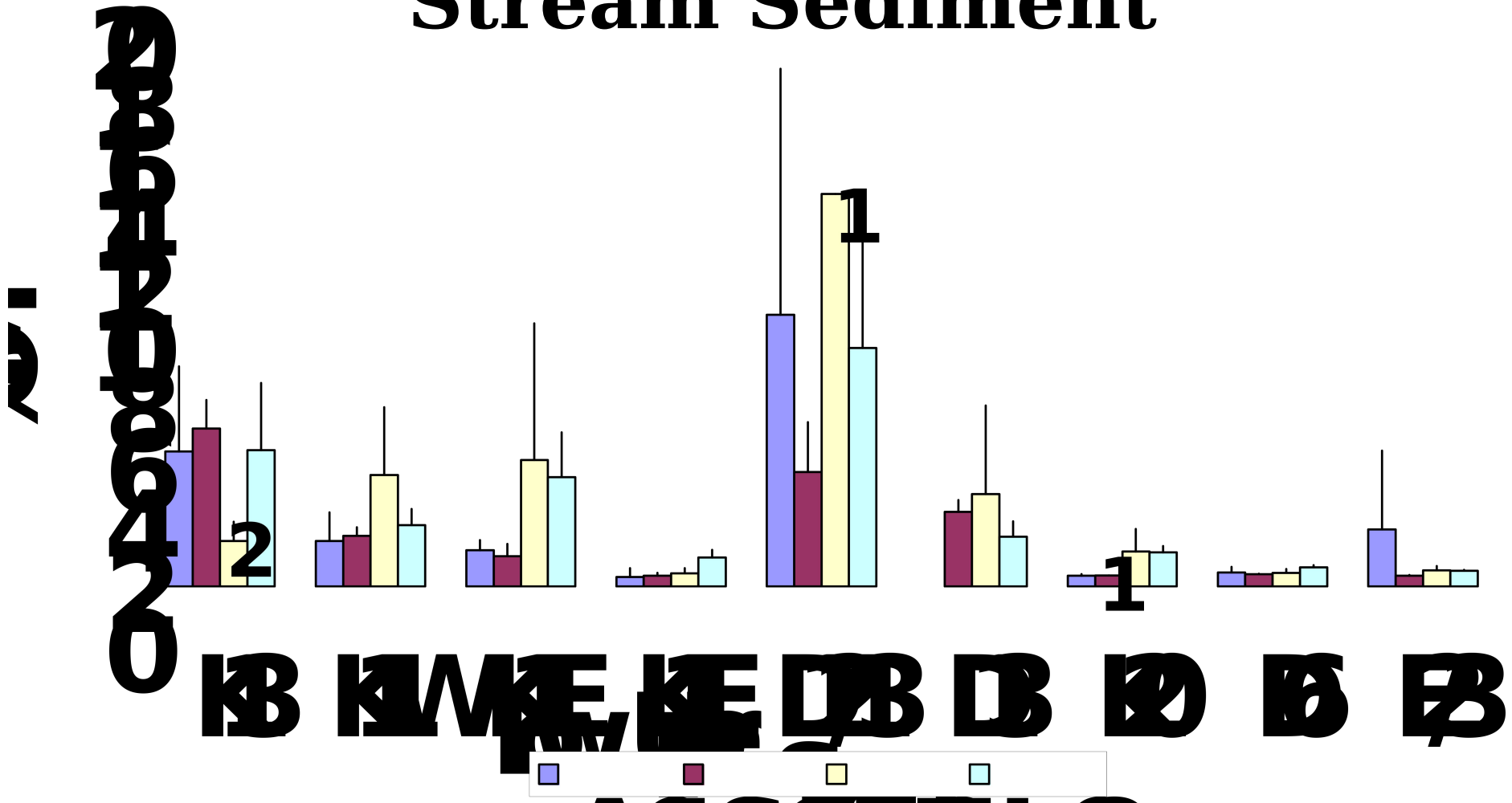
High daytime primary production in reference stream (K13)

Smaller diurnal dissolved oxygen changes with greater levels of land use (lower algal productivity)



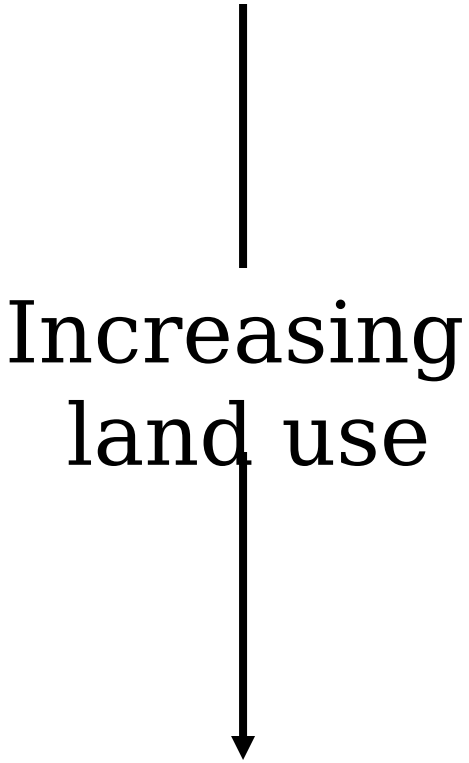
Median, quartiles, and outliers for dates with mostly clear weather in February and March (period of maximum primary production)

% Organic Matter in Stream Sediment

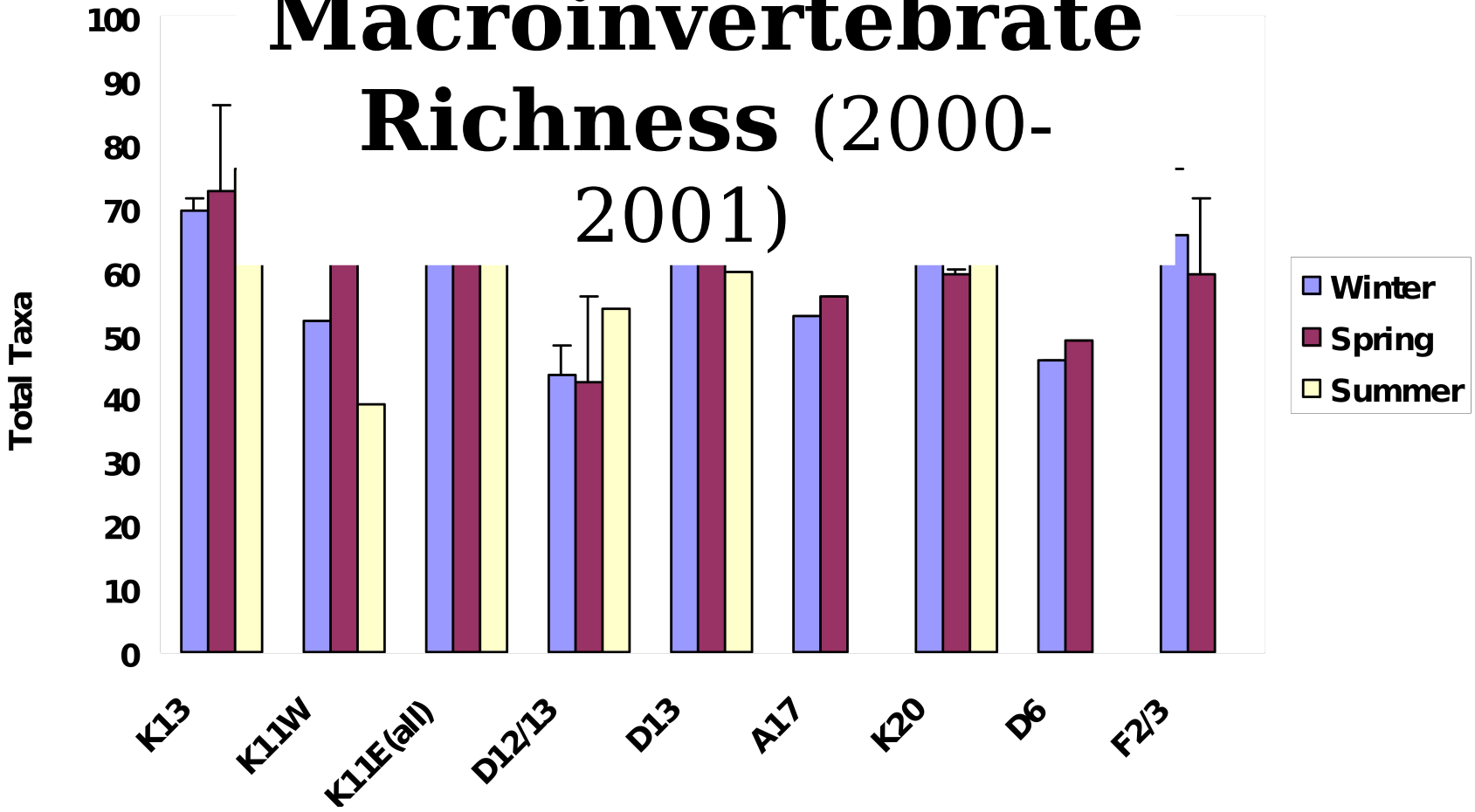


- Increasing intensity of land

Bedload Sediment Profiles

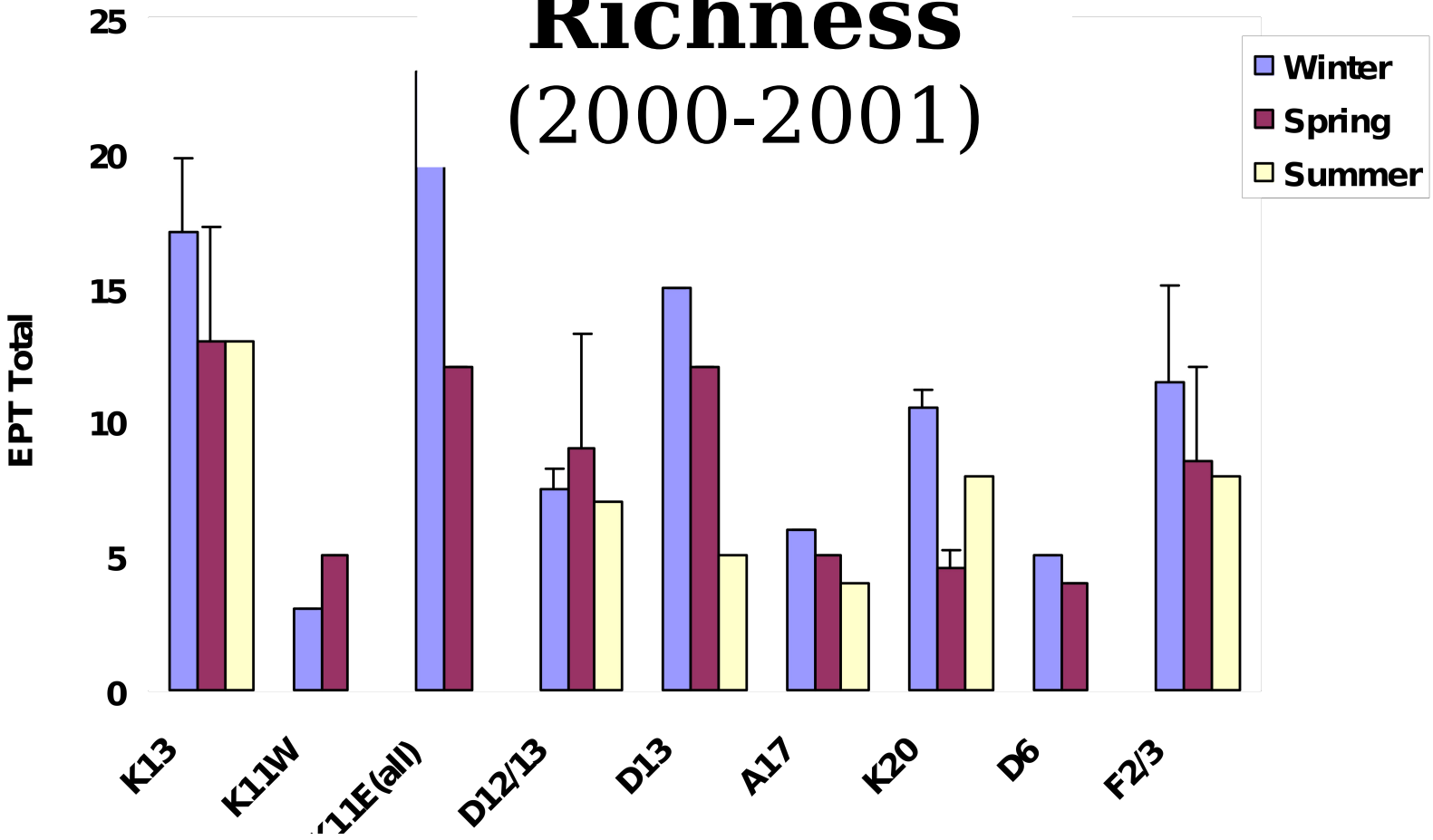


Total Macroinvertebrate Richness (2000-2001)



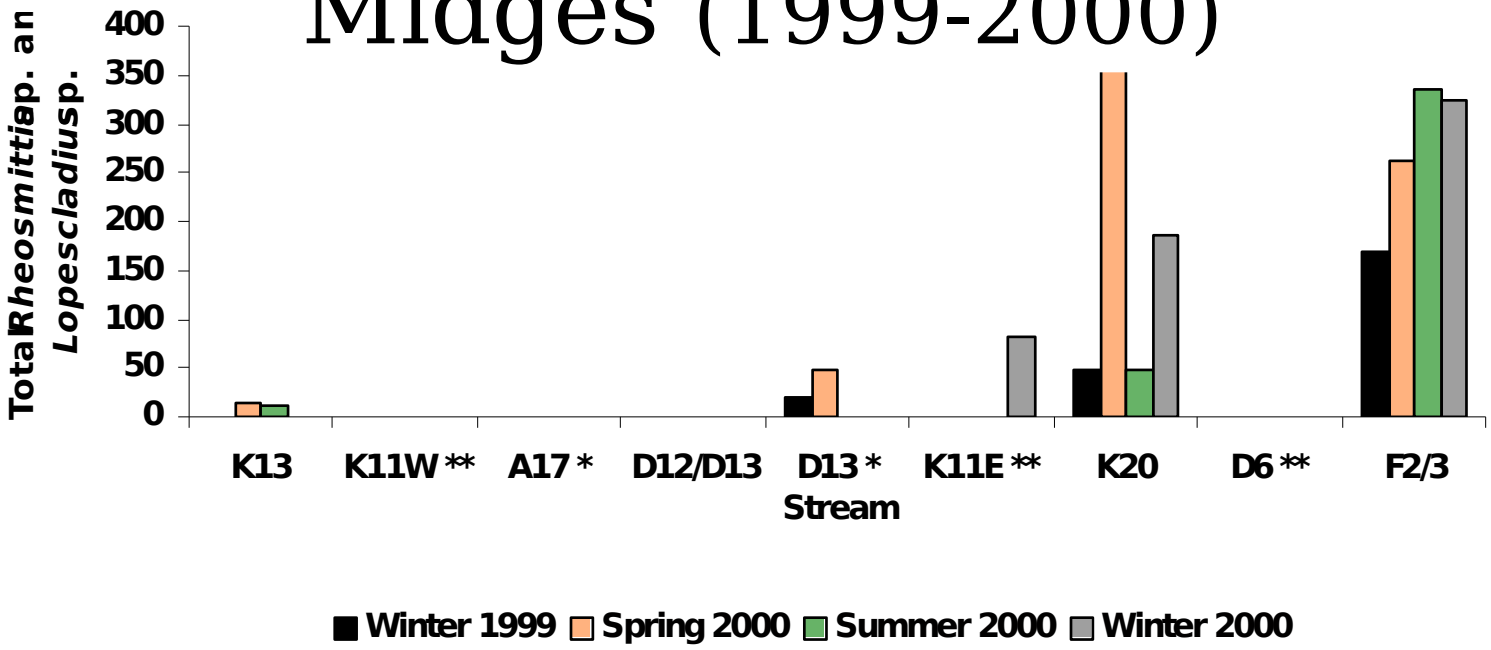
- Increasing land use→

EPT Richness (2000-2001)



- Increasing land use→

Abundance of Sediment-Tolerant Midges (1999-2000)

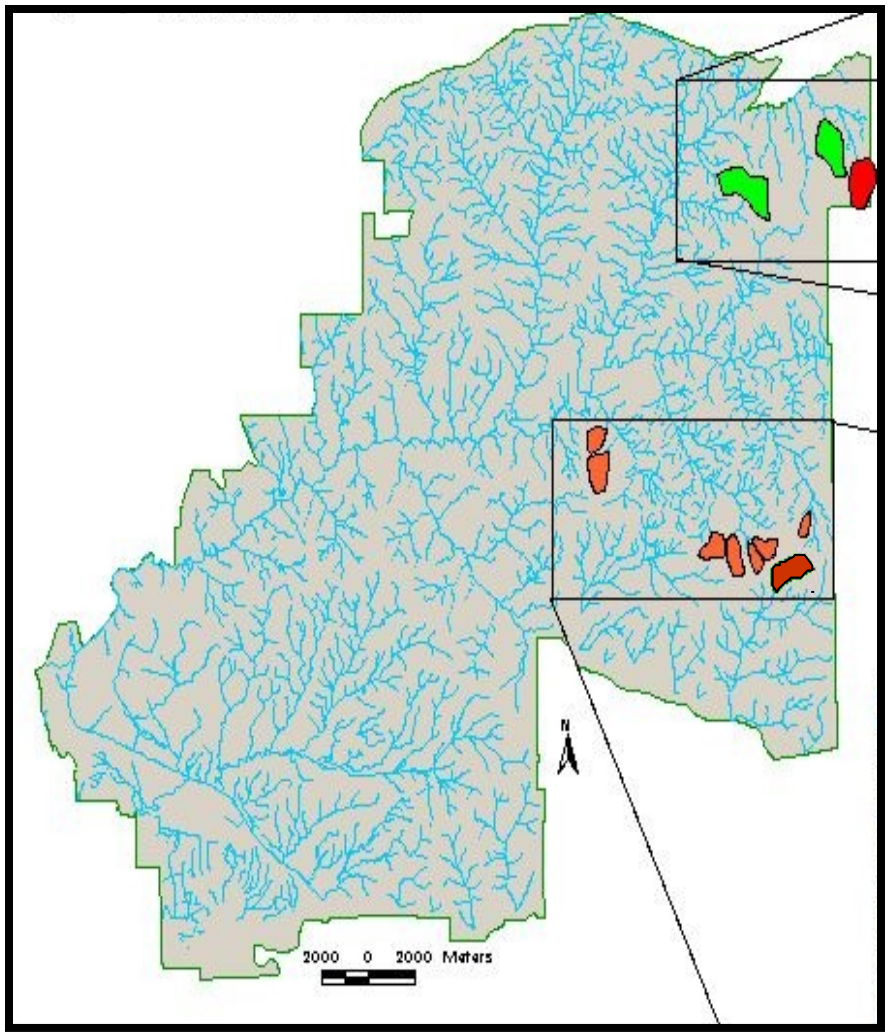


- Increasing land use intensity→

Potential stream indicators of catchment-scale impacts

- Suspended sediment and nutrient (NH_4, NO_3, PO_4) concentrations (baseflow, storms)
- Diurnal dissolved oxygen profiles (in-stream metabolism)
- Streambed organic matter content (habitat)
- Macroinvertebrate communities (various metrics at population and community levels)

* Indicators evaluated using a gradient analysis approach



- 1st to 2nd order stream catchments
- Catchments selected to provide gradient of disturbance severity
- Determine responses of potential indicators across disturbance severity gradient

*Reference catchments

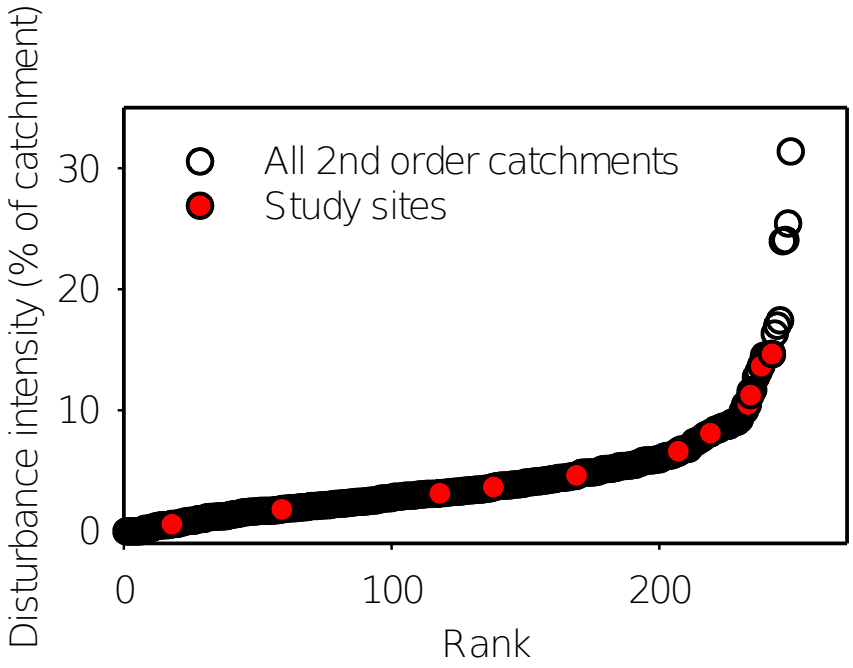
Disturbed catchments

Catchment-scale Disturbance Index

Measure of disturbance intensity - sum of:

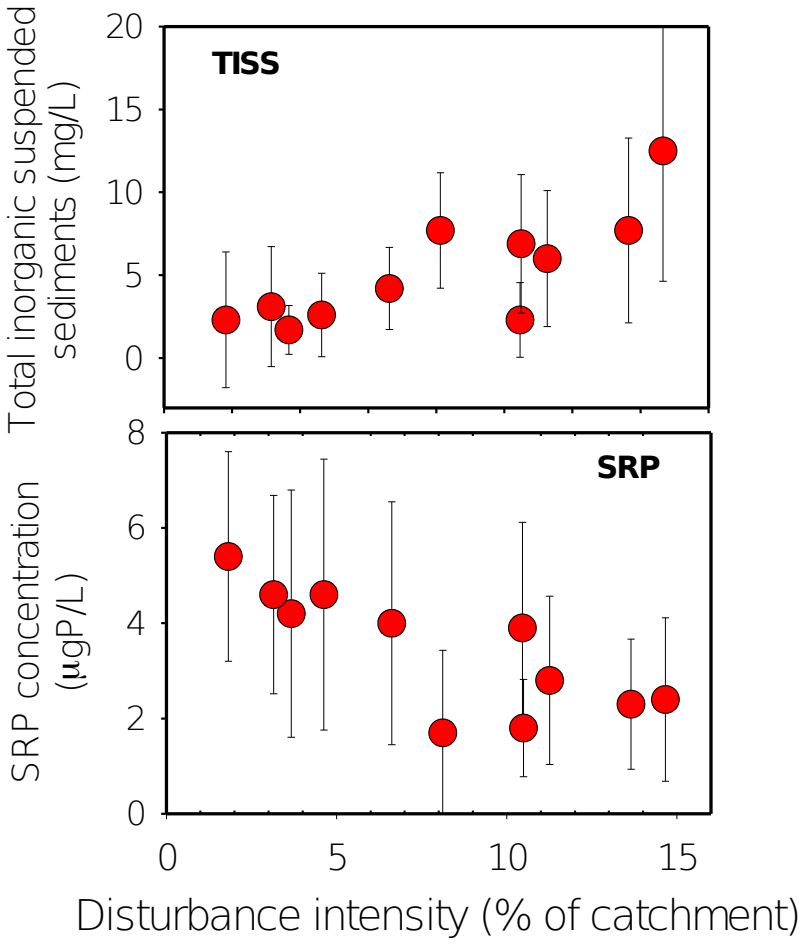
1) % Bare ground on slopes > 3% (TM imagery, DEM)

2) Road density (km/km2, converted to % of catchment area)

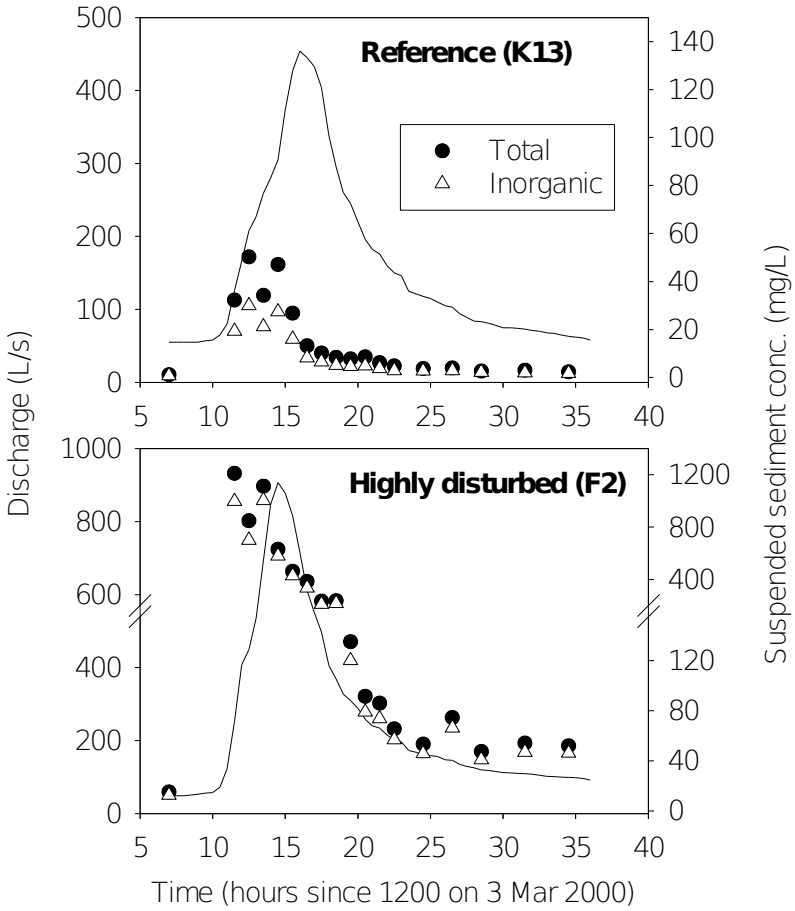


Indicator of land/water exchanges:

Baseflow chemistry

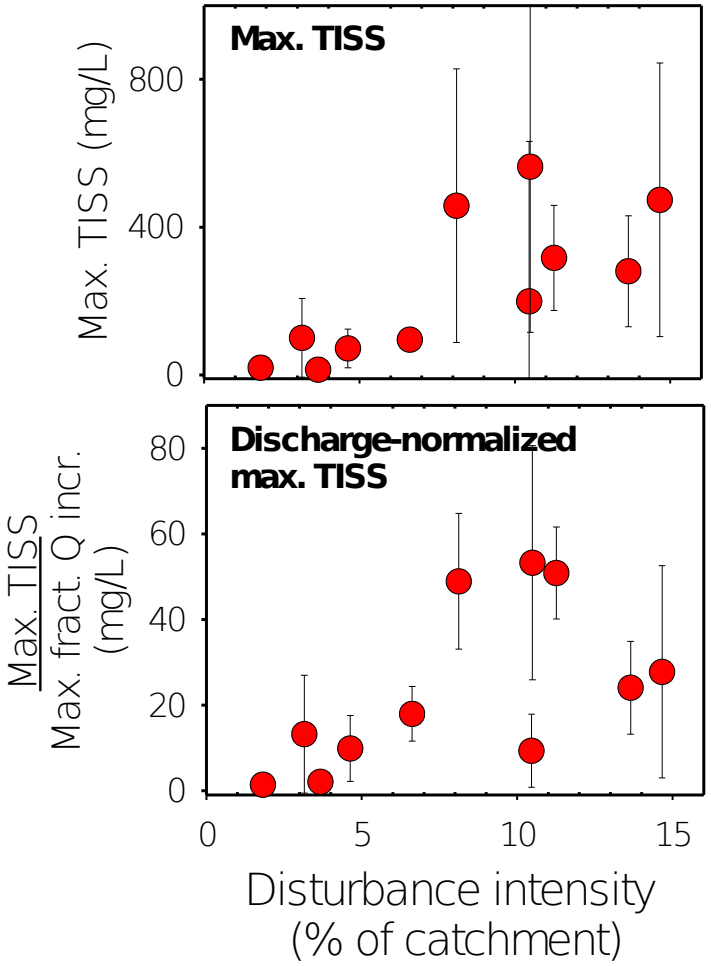


Greater increase in suspended sediments in disturbed catchments during storms



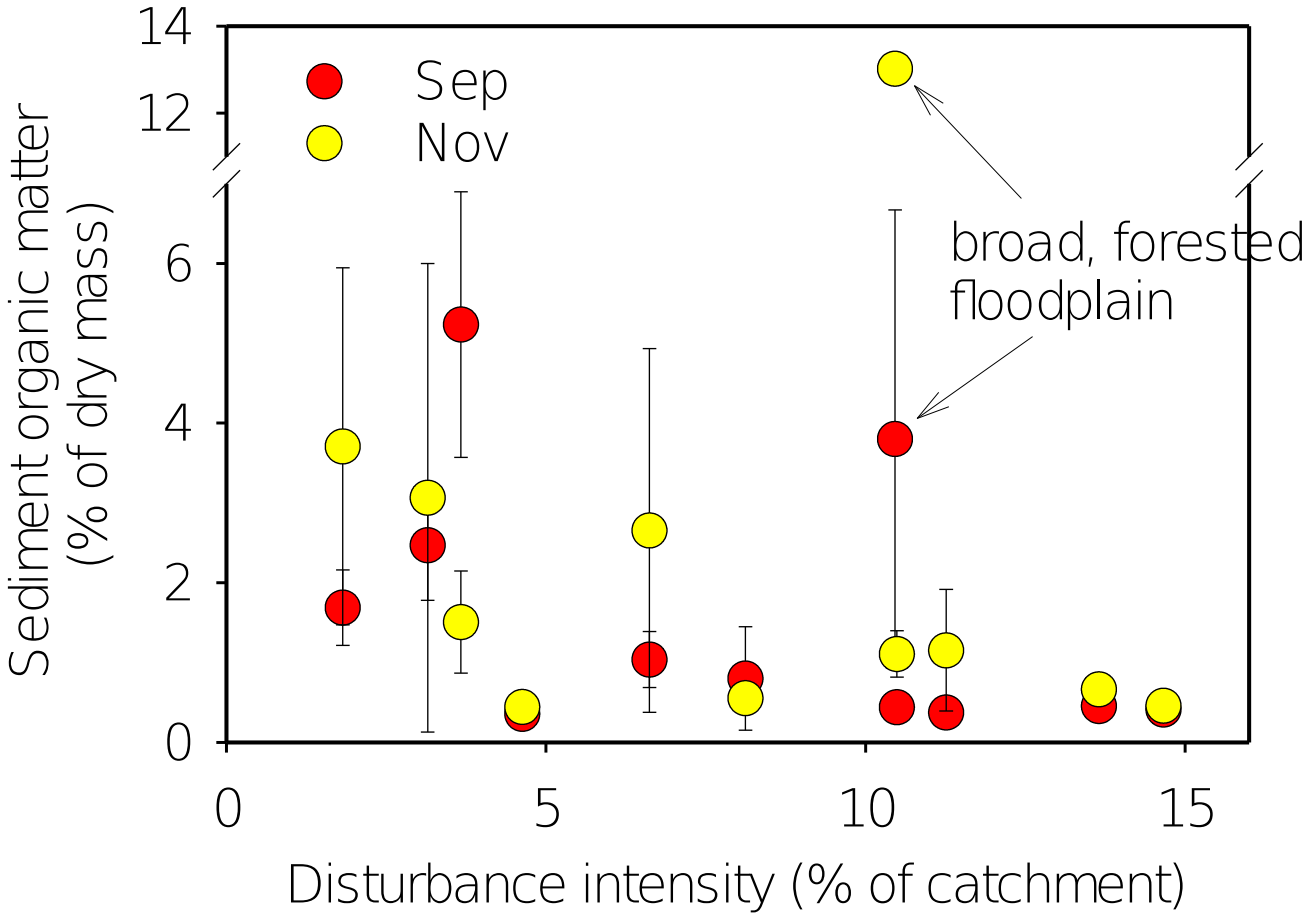
Indicator of land/water exchanges:

Storm chemistry

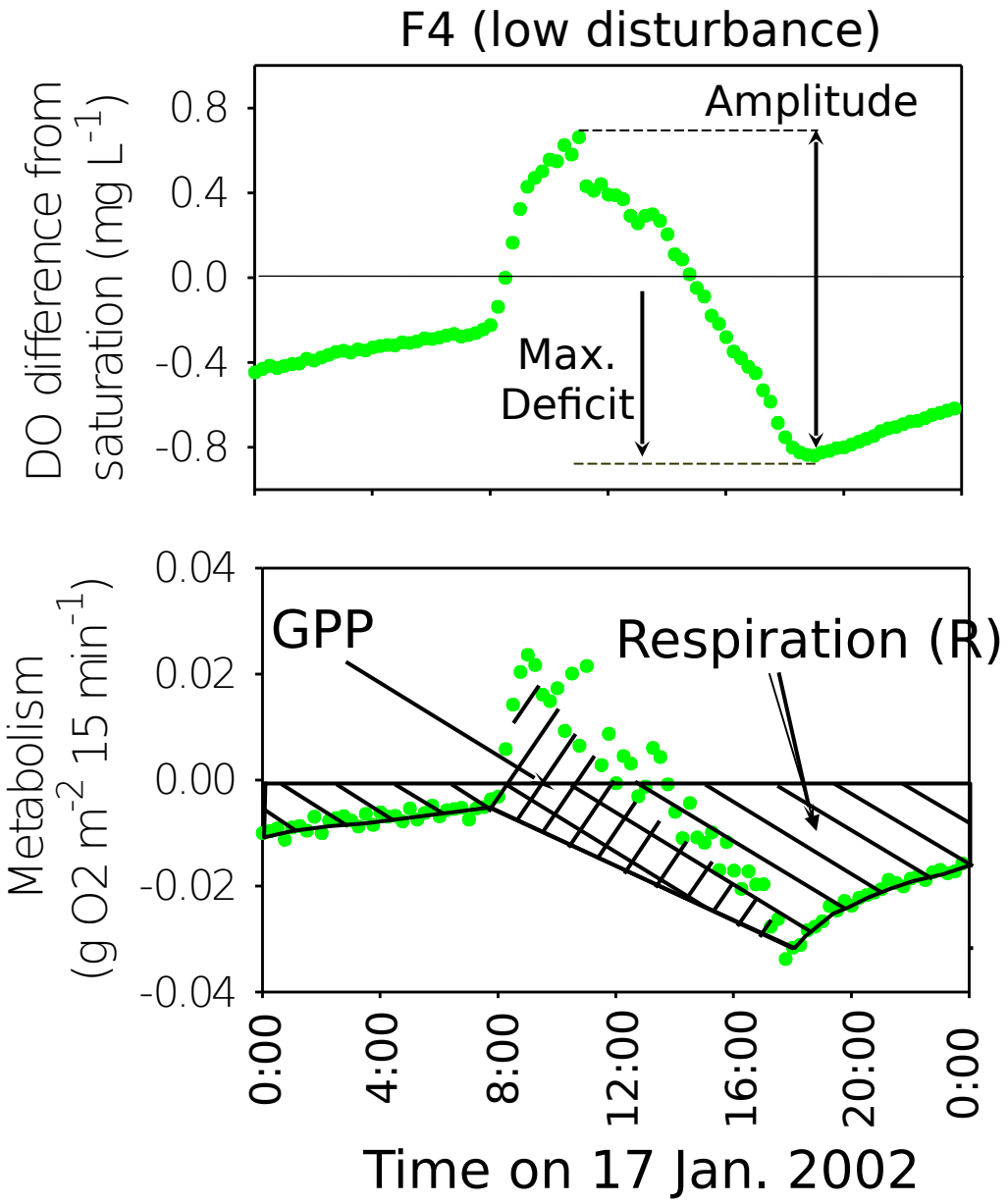


Indicator of stream habitat condition:

Sediment organic matter content



* Determining stream metabolism

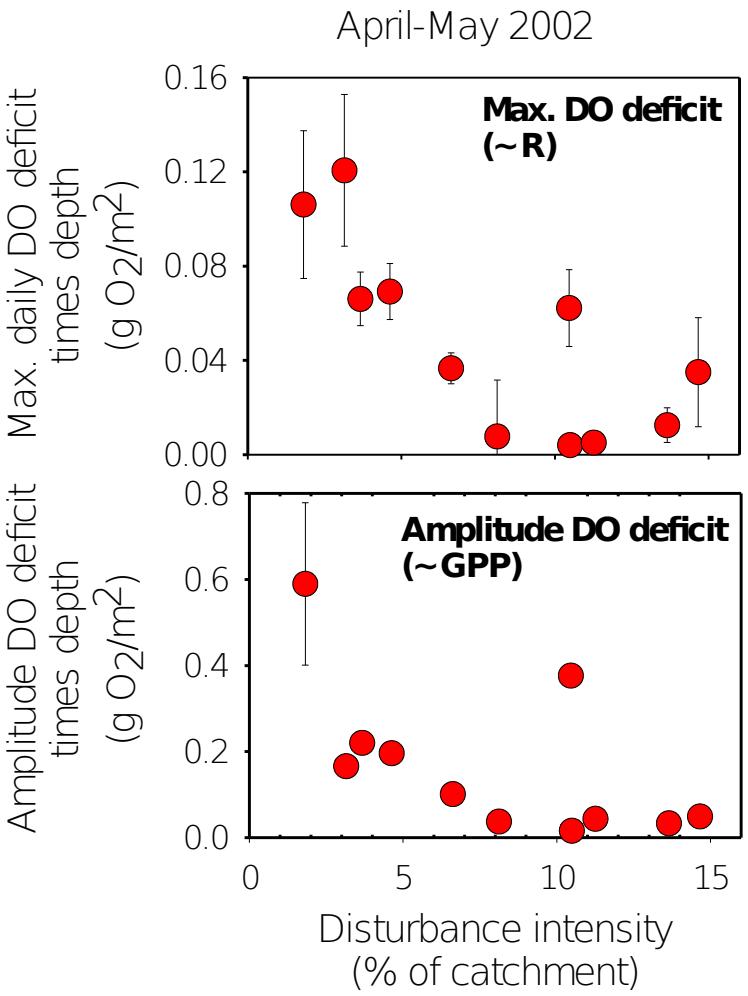


$$\Delta DO = GPP - R \pm E$$

DO difference from saturatio
- -DO concentration
- -Barometric Pressure
- -Temperature

Atmospheric exchange (E)
- -DO difference from saturatio
- -Reaeration coefficient (K_{O_2}) from NaCl/propane injection

* Indicator of stream metabolism:
Maximum DO deficit, Amplitude DO deficit



Indicator of stream biota:

Number of macroinvertebrate taxa (only significant in spring)

*

* Indicator of stream biota:

Density of sediment-tolerant midges

Goals of this Landscape Analyses

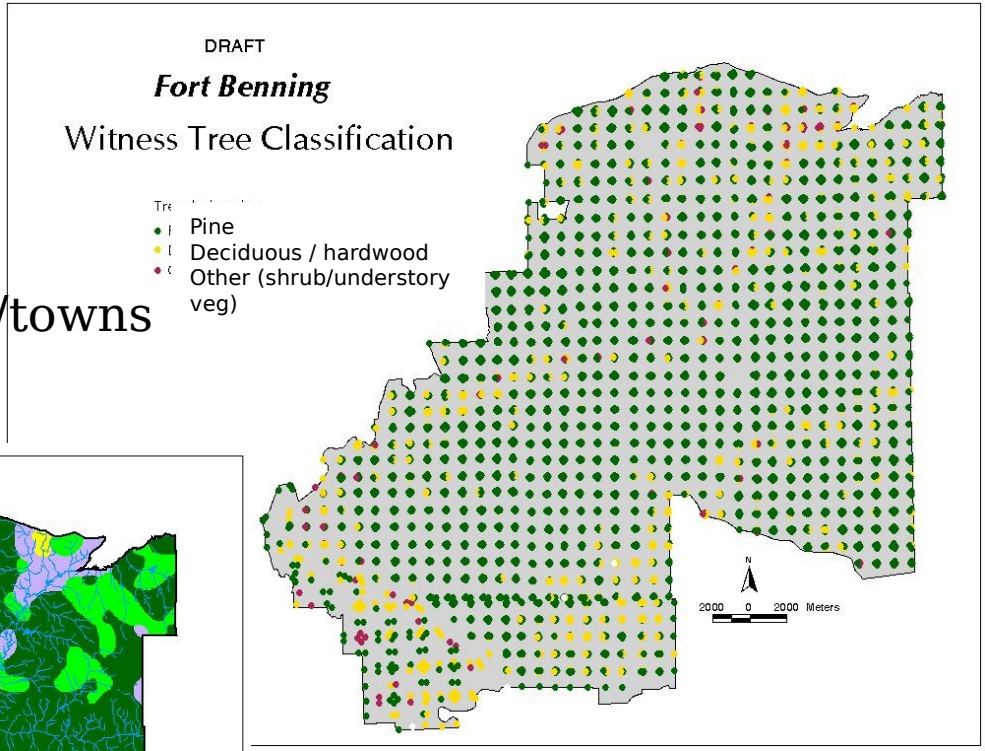
- To identify and map land cover trends that have occurred in recent human history at Fort Benning.
  - Data collection
  - Development of land cover maps
- To develop techniques to measure changes on the landscape.
  - Computation, summarization, and evaluation of landscape metrics

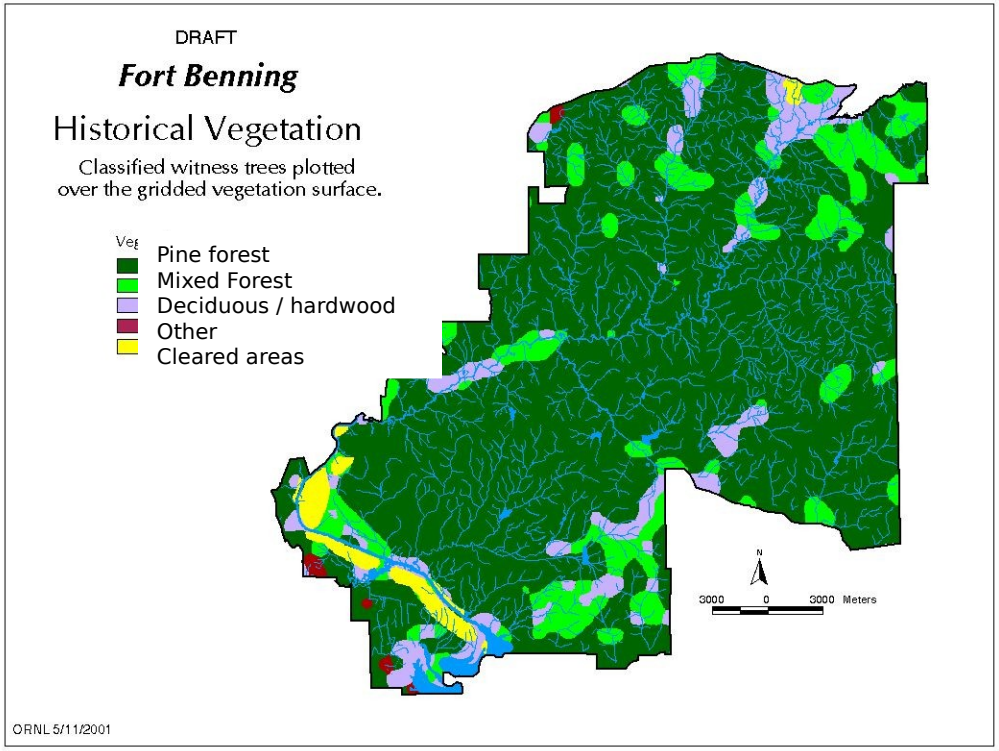
Technical Approach: Landscape Studies

- Explore data availability
- Develop comparable data sets over time
- Analyze changes in pattern and distribution of land cover over time
- Determine which landscape metrics are most useful for indicating change

Fort Benning Historical Vegetation - 1827

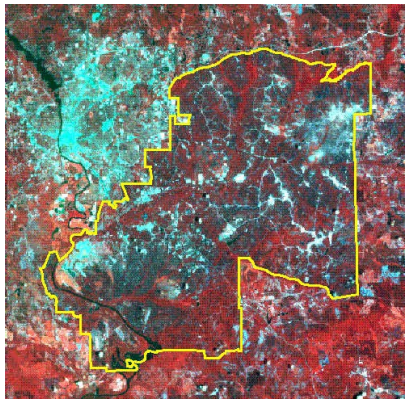
1. Witness tree data
2. Tree classification
3. Interpolation of surface
4. Estimation of cleared areas- large settlements/towns

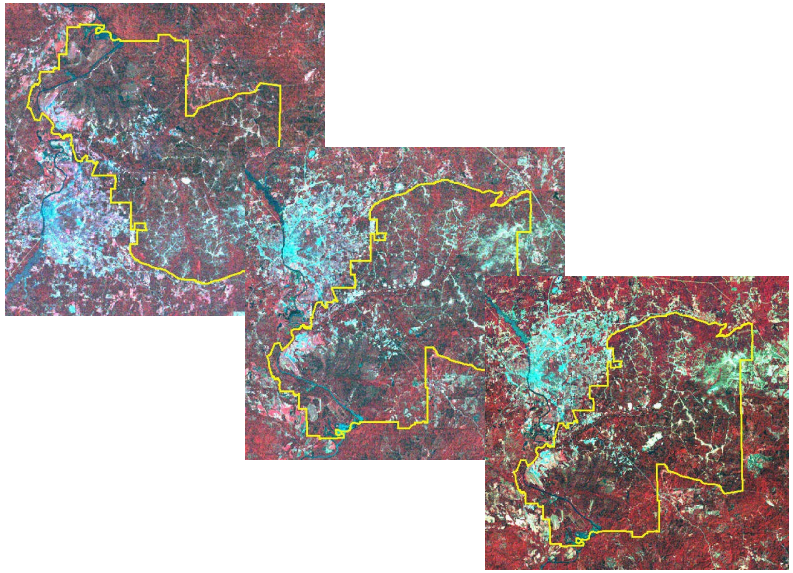




Contemporary Data Sources

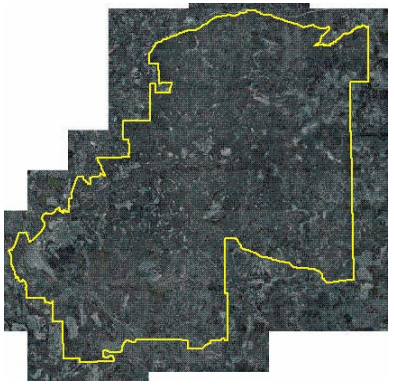
- LANDSAT 7 Enhanced Thematic Mapper (ETM+) July, 1999 (30m)
  - 2 scenes (path/row)
    - 019/38
    - 019/37
- North American Landscape Characterization (NALC) - Multispectral Scanner (MSS) triplicates (60m)
  - 1974, 1983/86, 1991

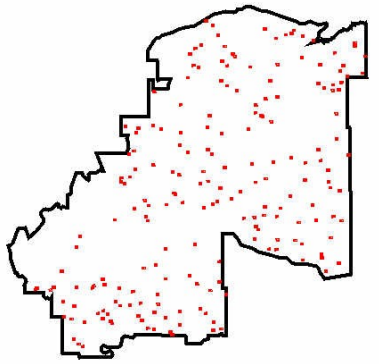


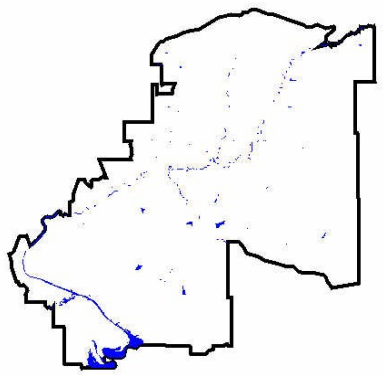


Reference Data

- February 1999 color digital orthophoto
- Land Cover Trend Analysis Data (LCTA)
- Streams







Classification

- Arc/Info 7.2.1, ArcView 3.2, Erdas Imagine
- Mosaicked/projected imagery using nearest neighbor resampling
- Unsupervised classification - 45 classes
- Used reference data to combine 45 classes into 6 land cover classes

- Created and applied a water mask in GRID to eliminate confusion between water and vegetation classes
- Removed clouds and cloud shadows
  - digitized shapes
  - overlaid shapes with orthophoto
  - refined boundaries and determined appropriate land cover class
  - plotted shapes with classified image, adjusted boundaries and merged

Land Cover Classes

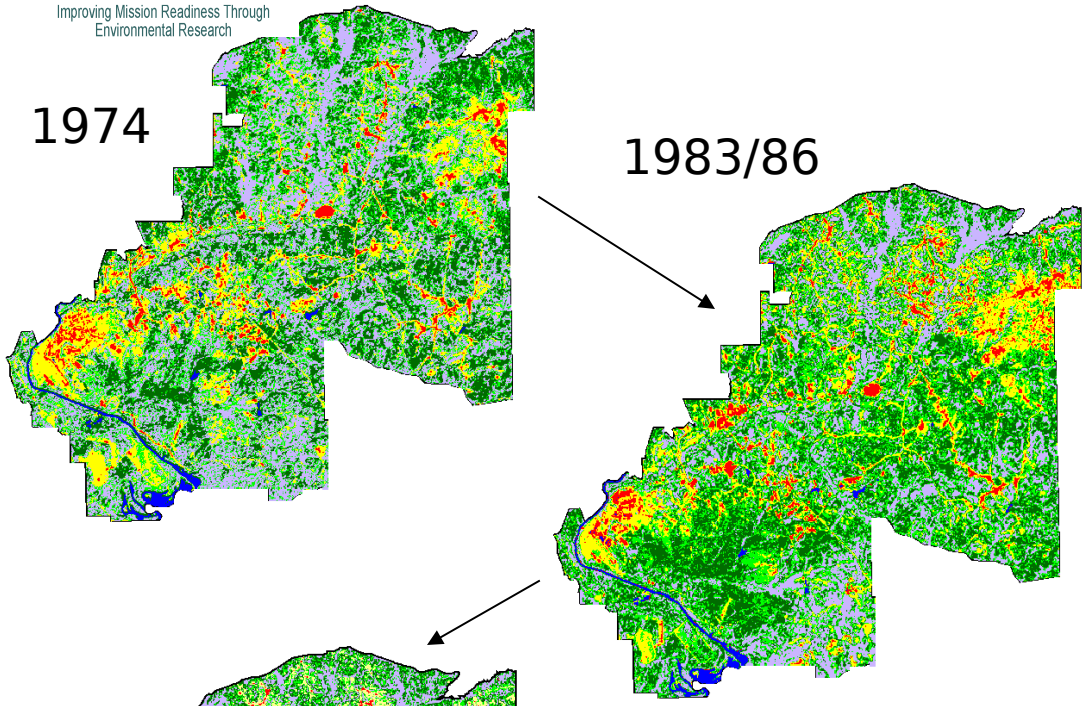
- Bare ground or developed areas such as buildings (highly reflective surfaces)
- Non-forest or cleared areas (ground cover present, includes lawns, and transitional areas)
- Deciduous forest (dense)
- Mixed forest (areas of deciduous and pine, widely spaced or sparse forest cover, and transitional areas between forest and non-forest)
- Pine forest (dense)
- Water

Classification Issues

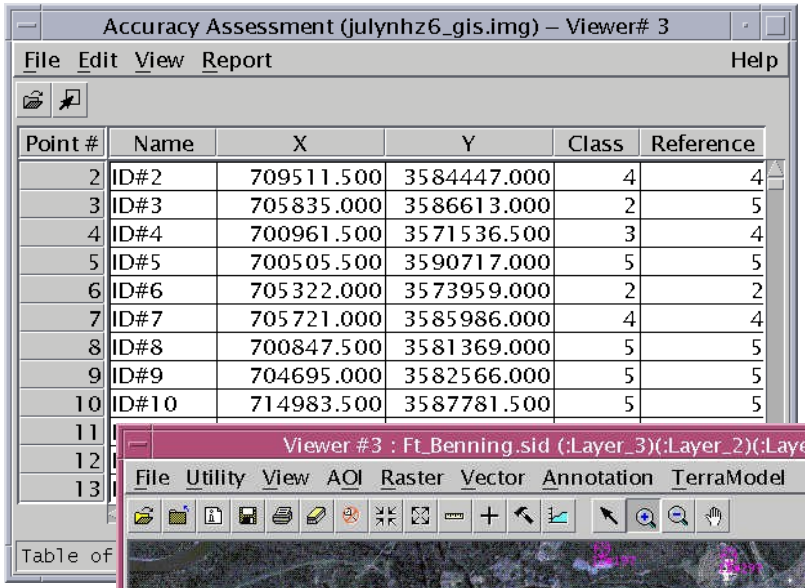
- The ability of this classification to differentiate forest classes is a concern
- Expected errors:
  - Pine and deciduous forest misclassified as mixed forest (over-represent mixed forest, under-represent pine and deciduous forest)

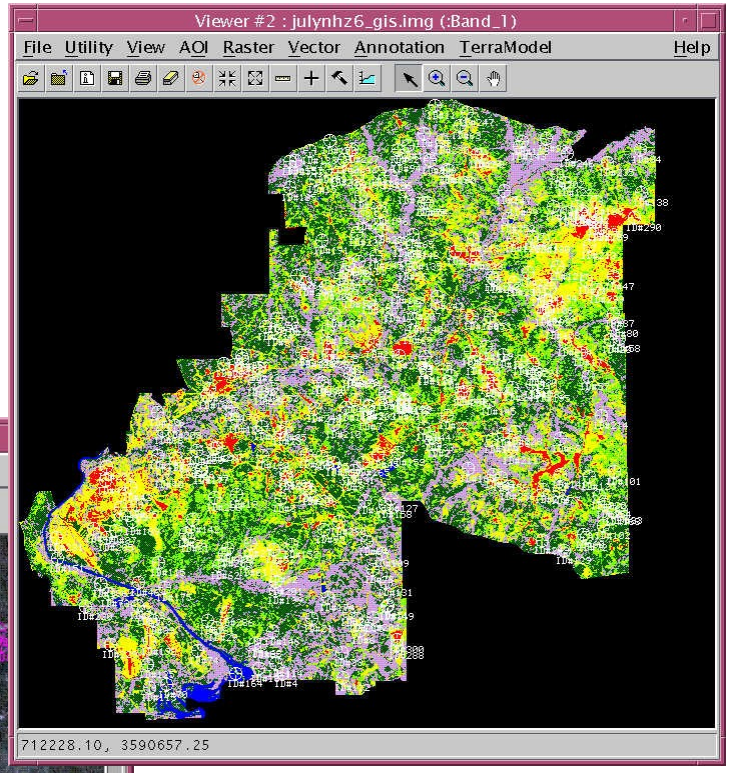
SERDP
Strategic Environmental Research and Development Program
Improving Mission Readiness Through Environmental Research

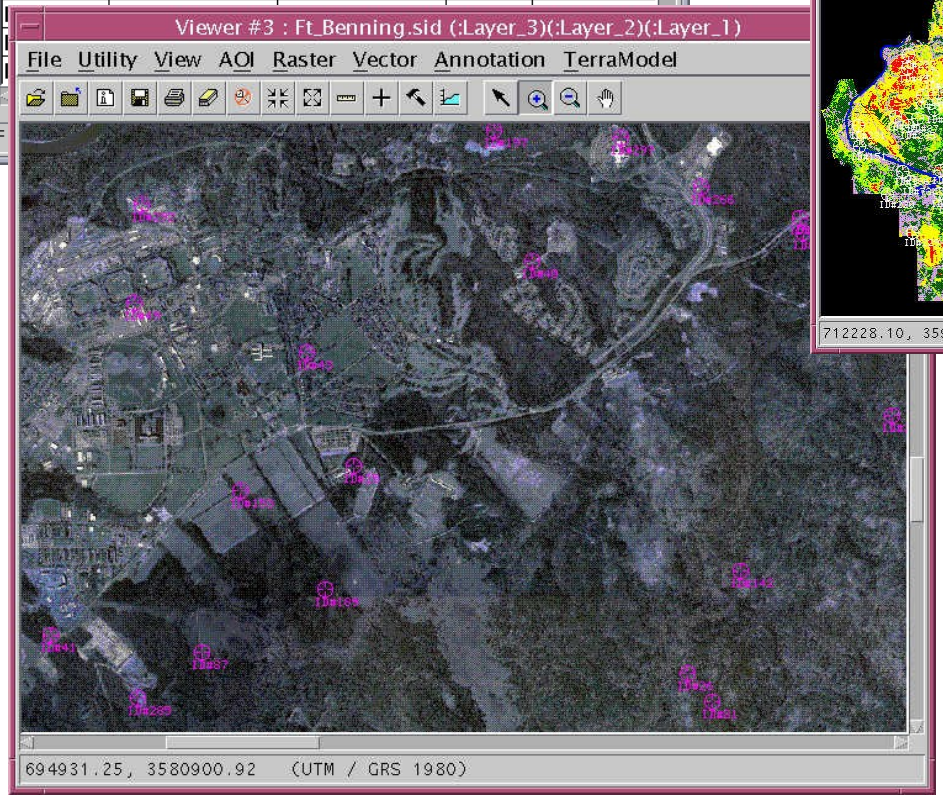
ornl
Oak Ridge National Laboratory


1974
1983/86
1991
1999
Ft. Benning
Land Cover Classification Key
Bare ground or developed areas such as buildings. (highly reflective surfaces)
Non-forest or cleared areas. (ground cover present, includes lawns)
Deciduous forest (dense)
Mixed forest (areas of deciduous and pine, widely spaced or sparse forest cover and transitional areas between forest and non-forest)
Pine forest (dense)
Water

1999 Land Cover Classification : Accuracy Assessme






Viewer #3 : Ft_Benning.sid (:Layer_3)(:Layer_2)(:Layer_1)
File Utility View AOI Raster Vector Annotation TerraModel
694931.25, 3580900.92 (UTM / GRS 1980)

Purpose: *to quantify the accuracy of the 1999 land cover classification.*

Tools:

- ERDAS IMAGINE Software
- 1999 Classified Land Cover from ETM+ Image
- 1999 Digital Color Orthophoto 0.5 m resolution

Accuracy Assessment -1999 LandSAT ETM Classification resampled to 60m resolution

Reference Class	*#Correct*	*Producer' s*	*User's*
Example			
Class 3 38	50	34	89.47% 68%
(deciduous forest)			
			0%
			2.0%

Example: Producers versus user's accuracy

Producers: 89.47% of deciduous areas (as identified on orthophoto) have been correctly identified as deciduous c

%

Users: 68% of areas called deciduous on classified map ar deciduous on ground (or on orthophoto in this case)

*Accuracy Assessment - Fort Benning Landscape Analysis
30 m Land Cover Classification Resampled to 60 m Resolutio

Kappa Statistic = 0.6900
Class 1 Kappa = 0.8049
Class 2 Kappa = 0.6602
Class 3 Kappa = 0.6626
Class 4 Kappa = 0.7368
Class 5 Kappa = 0.6359

Overall accuracy = 75.20%

(Accuracy of 30 m resolution = 85.

July 1999 - ETM+ Classified Image (resampled to 60 m)

	Reference	Class	#Correct	Producer's Accuracy	Use Accu
Class 1 (bare/developed)	45	50	42	93.33%	84%
Class 2 (non-forest vegetation/transitional)	44	50	36	81.82%	72%
Class 3 (deciduous forest)	38	50	34	89.47%	68%
Class 4 (mixed forest)	79	50	41	51.90%	82%
Class 5 (pine forest)	44	50	35	79.55%	70%

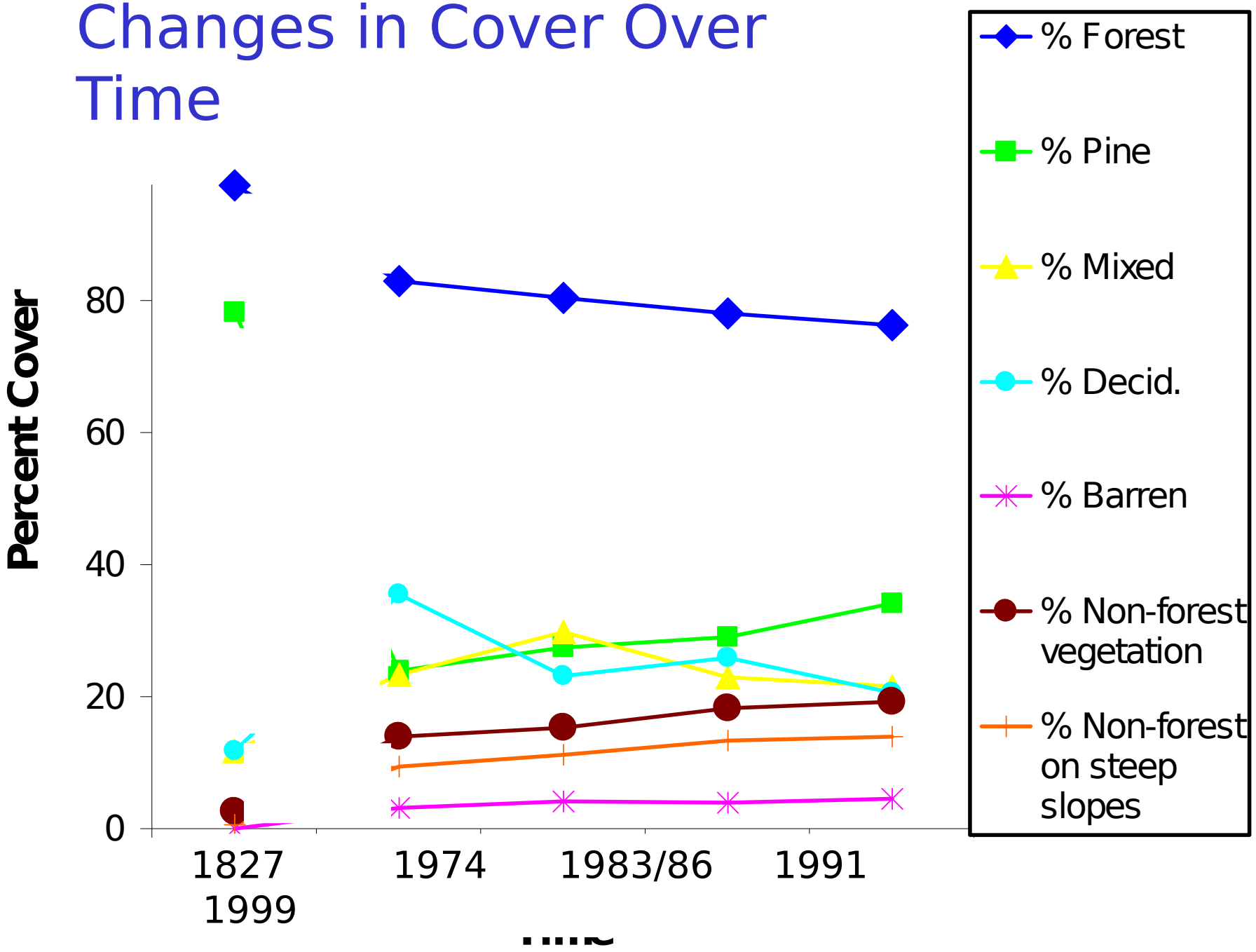
Landscape Metrics

- Indicators of fragmentation
  - describe the size, shape, and distribution of relatively homogenous “patches” of vegetation or land cover
- Software
  - Analytical Tools Interface for Landscape Assessments (ATtILA)
    - an ArcView extension developed cooperatively by the Environmental Protection Agency and the Tennessee Valley Authority
    - Can provide metrics by reporting unit
  - FRAGSTATS
    - developed by Kevin McGarigal and Barbara Marks
    - Can report metrics by cover type

Selected Forest Patch Metrics- ATtiLA

Metric	1827	1974	1983/86	1991	1999
# Forest Patches	3	202	238	248	395
Mean Patch Size	239,833,200	3,000,403	2,467,845	2,291,530	1,408,557
Largest Patch Size	719,348,400	563,396,400	541,213,200	525,078,000	546,213,600
Shannon-Weiner Diversity Index	0.6312	0.254	0.2381	0.2338	0.22
Simpson's Diversity Index					

Changes in Cover Over Time



Unfiltered versus Filtered Land-Cover Data

Unfiltered Data - ETM+ 1999 land-cover classification, 30m resampled to 60m resolution.

Filtered Data - above land-cover classification, passed through a smoothing filter to compensate for isolated and/or misclassified pixels. Filter consisted of a 3x3 moving window that assigned the majority value to the center pixel.

Selected Class Metrics Pine Forest Class (FRAGSTATS)*

Metric	1974	1983/86	1991	1999
% Landscape	25.1051	26.4424	31.1604	36.7393
# Patches	11,859	16,021	16,790	17,450
Mean Patch Size	1.0795	0.9393	0.9532	1.0119
Patch Density (#/100ha)	22.2454	30.0526	31.4911	32.7331
Total edge (m)	4,311,480	5,777,820	6,108,900	6,501,300

*Note: results present the unfiltered land-cover data

Selected Class Metrics Pine Forest Class (FRAGSTATS)*

Metric	1974	1983/86	1991	1999
%Landscape	25.1051	26.4424	31.1604	36.7393
#Patches	1546	2478	1902	1307
Mean Patch Size (ha)	11.9866	7.8767	12.0931	20.7492
Patch Density (#/100ha)	2.0944	3.357	2.5767	1.7706
Total edge(m)	2,726,640	3,316,260	3,616,620	3,376,440

*Note: results present the filtered land-cover data.

Selected Class Metrics Non-Forest Class (FRAGSTATS)*

Metric	1974	1983/86	1991	1999
% Landscape	15.6696	16.3422	19.1875	21.3374
# Patches	8237	8950	9859	12,325
Mean Patch Size	1.0141	0.9734	1.0376	0.9229
Patch Density (#/100ha)	15.4512	16.7886	18.4914	23.1195
Total edge (m)	2,527,980	2,839,860	3,197,040	4,095,420

*Note: results present the unfiltered land-cover data.

Selected Class Metrics Non-Forest Class (FRAGSTATS)*

Metric	1974	1983/86	1991	1999
% Landscape	14.9087	16.30115	19.4853	19.1049
# Patches	931	919	1199	1616
Mean Patch Size	11.8205	13.0936	11.9959	8.7267
Patch Density (#/100ha)	1.2613	1.245	1.6243	2.1893
Total edge (m)	1,704,120	1,894,560	2,136,120	2,235,360

*Note: results present the filtered land-cover data.

Major Results

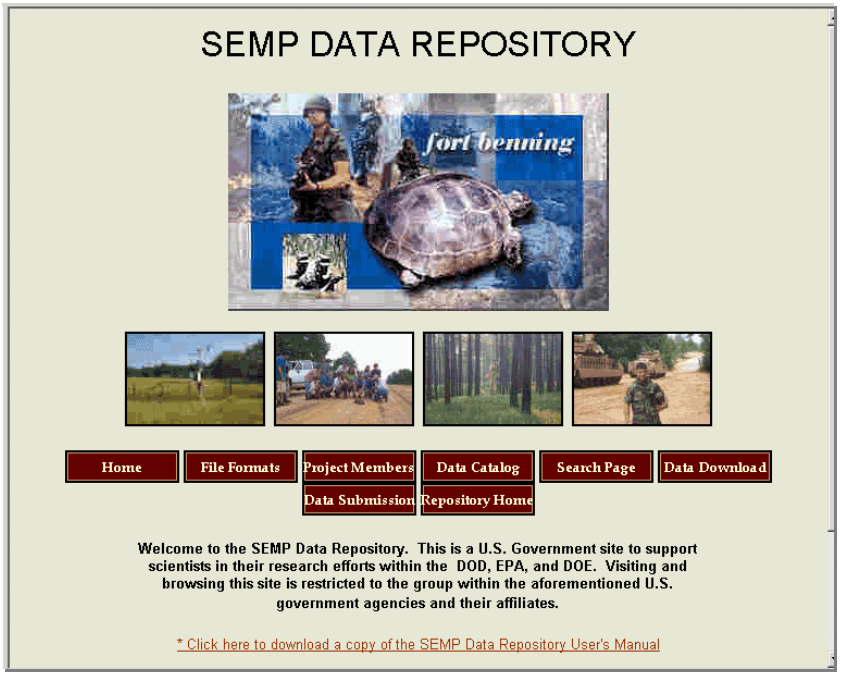
- **Vegetation maps developed from different data sources can be compared**
- **Changes over time occurred in the vegetation at Forest Benning**
  - 1827 to 1974
    - Percent cover of forest declined
    - Pine coverage decreased
    - Increase in deciduous, mixed and nonforest cover
  - 1974 to 1999
    - Gradual increase in the nonforest vegetation (esp. on slopes)
    - Decline in cover of forest vegetation
      - Increase in pine cover
      - Decrease in deciduous cover

(http//www.esri.com/library/userconf/proc01/professional/papers/pap765/p765

The most useful metrics for distinguishing changes in land cover classes at Fort Benning

- Percent cover
- Total edge (with border)
- Number of patches
- Mean patch area
- Patch area range
- CV of patch area
- Perimeter area ratio
- Euclidean nearest neighbor distance
- Clumpiness

Submitted Historical Data, Metadata and Reports to the SEMP Data Repository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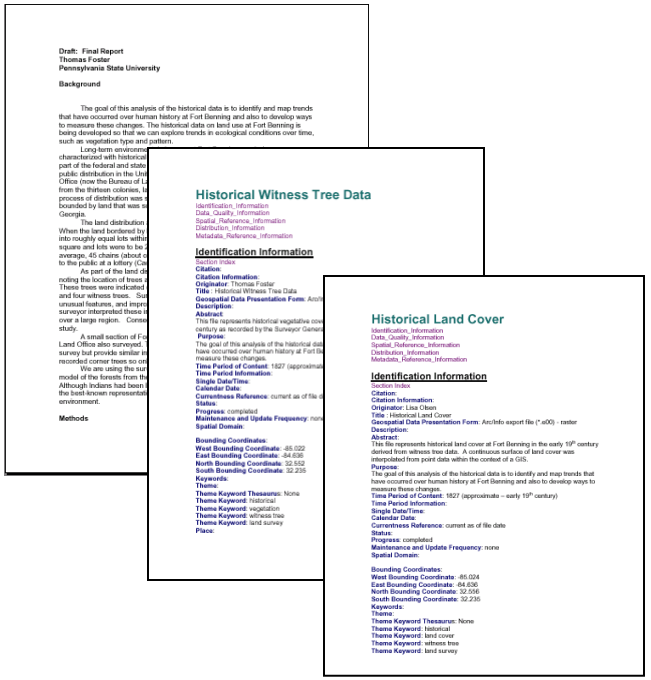
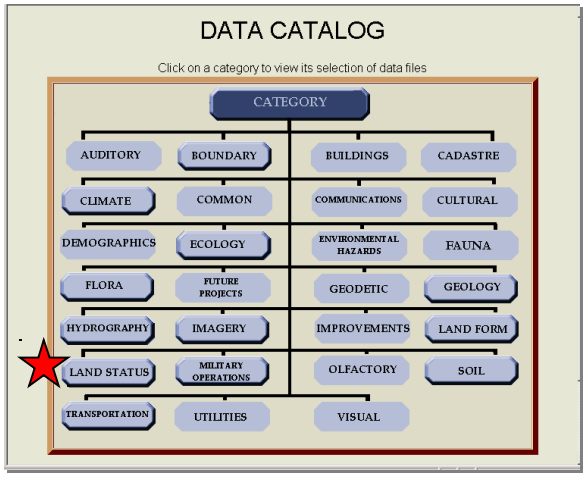
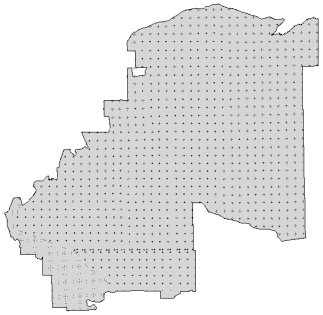
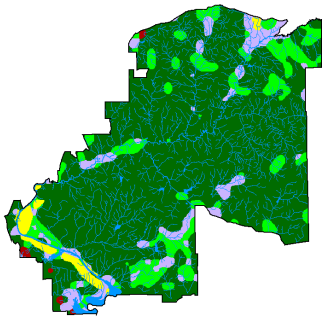
Welcome to the SEMP Data Repository. This is a U.S. Government site to support scientists in their research efforts within the DOD, EPA, and DOE. Visiting and browsing this site is restricted to the group within the aforementioned U.S. government agencies and their affiliates.
* Click here to download a copy of the SEMP Data Repository User's Manual







Witness Tree - Point Data



Historical Land Cover

Other Data Entered into SEMP Repository

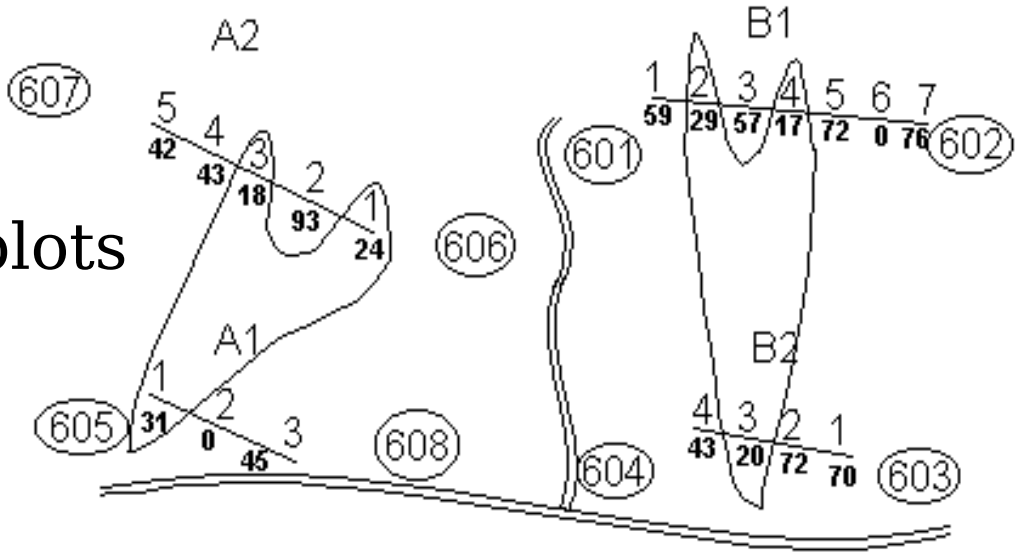
- Understory vegetation
- Microbial Community
- Benthic invertebrates
- Storm chemistry data

Experiment Established in K11

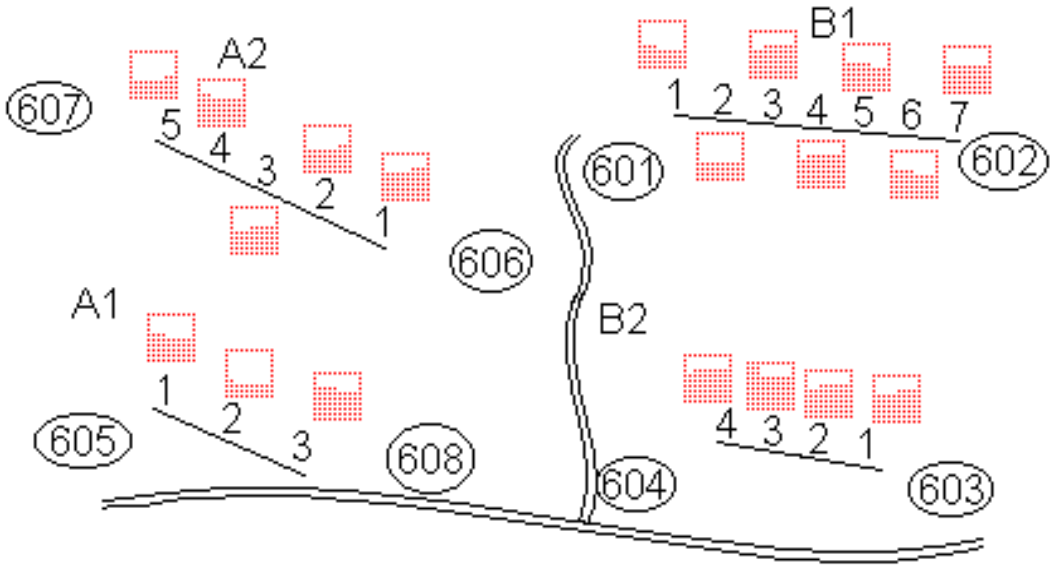
Pre- and post-disturbance monitor
- Canopy characteristics
- Understory vegetation
- Soil microbial community
- Storm water runoff
- Benthic invertebrates
- Erosion

General Patterns from K11 Experimental Site

Oldest trees in plots



% Canopy cover



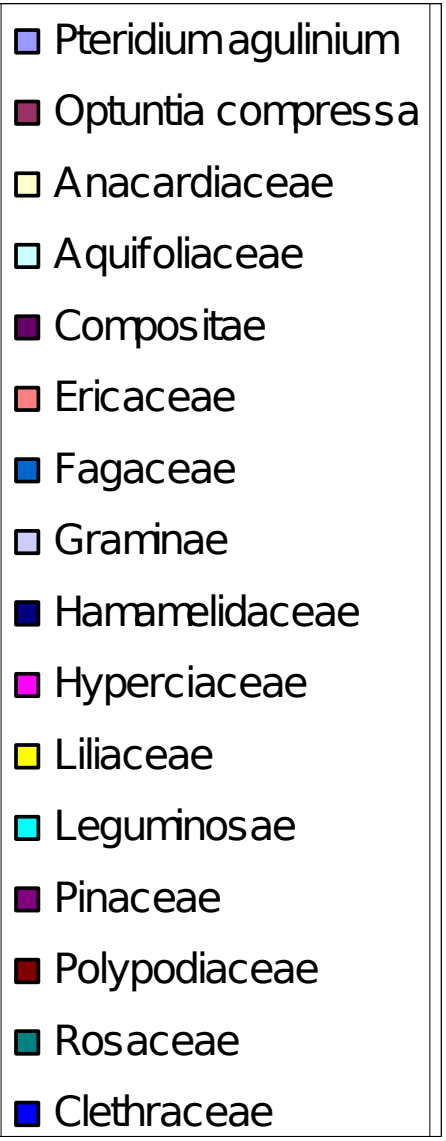
Experiment for Testing of Indicators

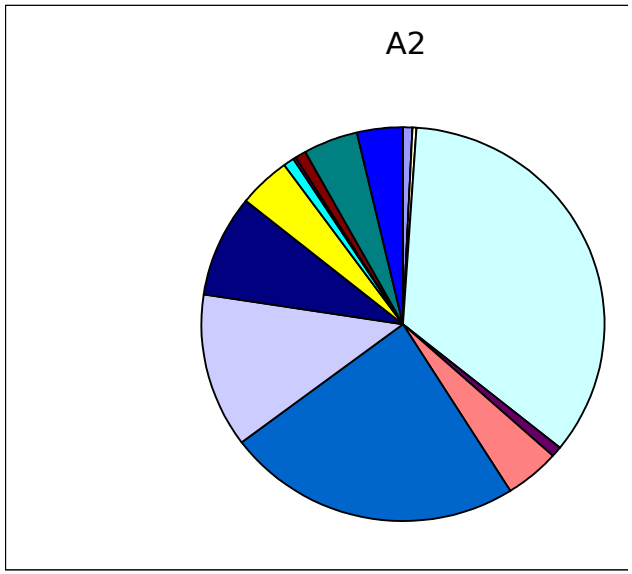
- Jan 2001 - K11 site selected
- Feb 2001 to April 2002- baseline data collected
- May 2002 – Understory fire
- June to Oct 2002- Post-fire data collection
- Oct or Nov 2002 – Thinning
- Dec 2002 to Oct 2003 – Post thinning data collected

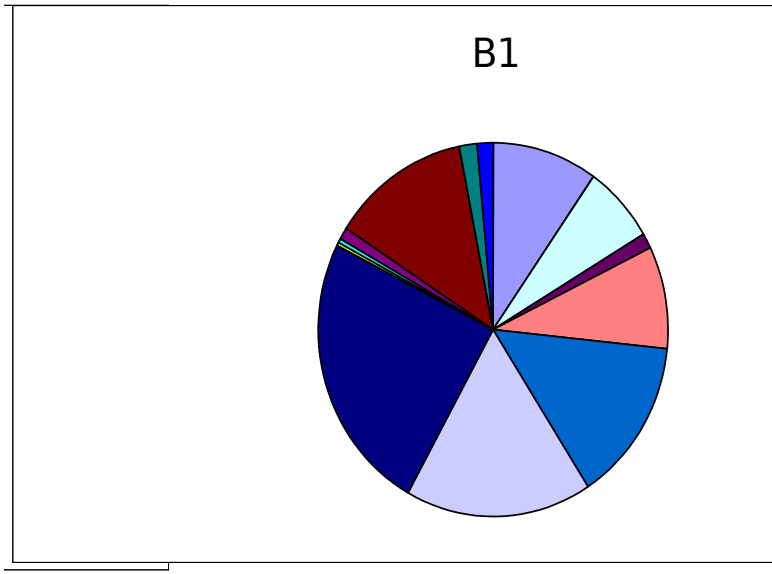
Coordination with other SEMP and SERDP projects

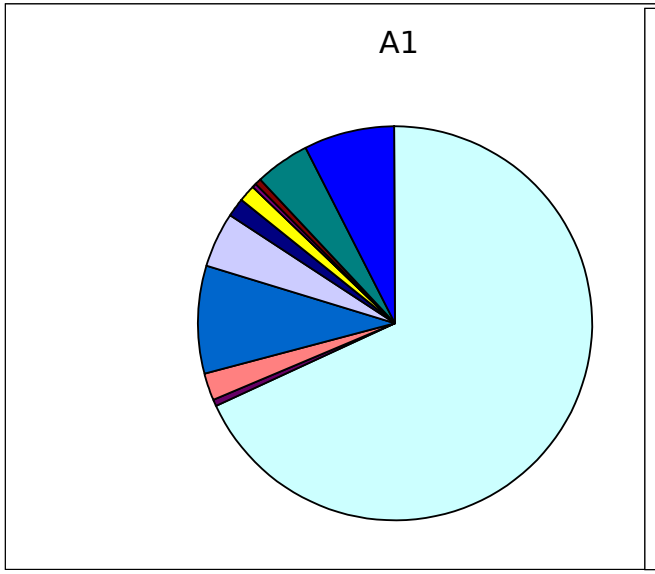
- **Garten and Ashwood** (soil carbon and nitrogen)
- **Collins and Dilustro** (soil respiration, temperature and moisture)
- **Ustin and Olstead** [hyperspectral data (primarily AVIRIS) to map and model the spread of invasive weeds]
- **Mulholland** (co-location of steam sampling sites)

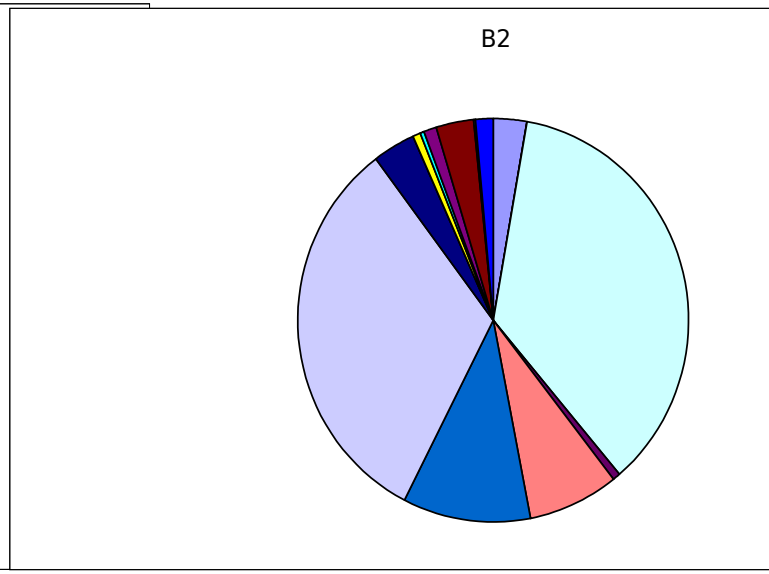
Life Form Distributions of Sample Sites











Products

Publications:

Journal, national or international (published or in press): 4

Journal, national or international (in review or submitted): 1

Journal, other (in review or submitted): 3

Other: 2

Presentations:

Professional meetings: 20

Other meetings: 7

Integration

Contributions to Other SEMP Projects

- Criteria for selecting a suite of indicators
- Protocol for selecting indicators
- Data from our studies on indicators: terrestrial, stream, and soil microbes
- Historical vegetation map
- Disturbance experiment

Coordination with Other SEMP Projects

- Baseline information provided by ECMI and LCTA
- Co-location of sampling sites and sharing of data with other SEMP projects
    - Storm hydrological chemistry
    - Stream macroinvertebrates
    - Soil samples
- A comprehensive picture of changes in microbial community structure

Coordination with Other SERDP Projects

- "Application of Hyperspectral Techniques to Monitoring and Management of Invasive Weed Infestation" is using hyperspectral data (primarily AVIRIS) to map and model the spread of invasive weeds at Fort Benning in coordination with our site specific data
- "A Regional Simulation to Explore Impacts of Resource Use and Constraints" is building upon our data and other ECMI information to integrate environmental effects of on-base training and testing and off-base development and other decisions
- "Riparian ecosystem management at military installations determination of impacts and evaluation of restoration and enhancement strategies" is co-locating some stream sampling sites and using some of our stream ecological indicators.